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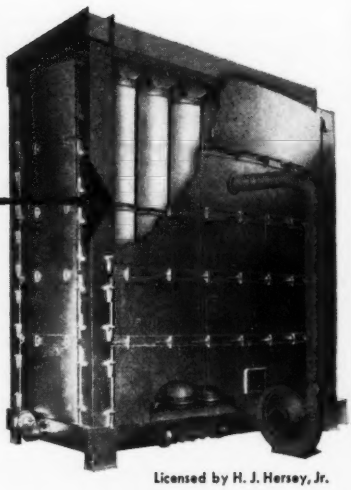

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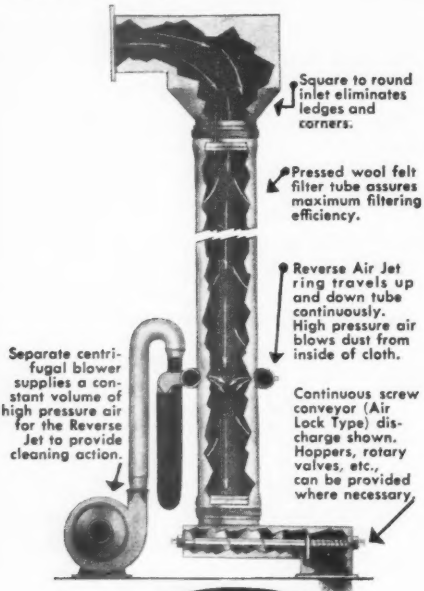
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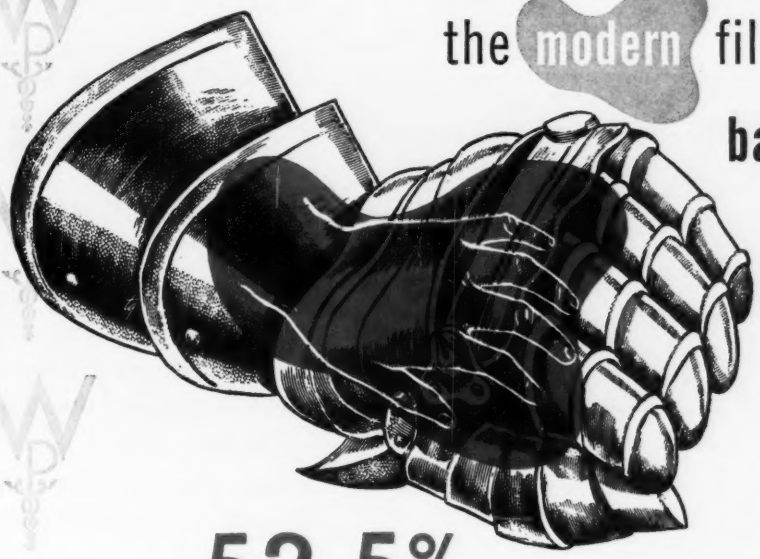

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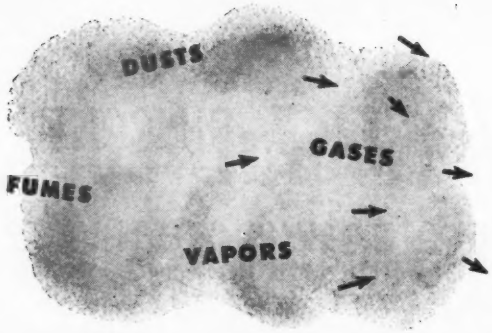

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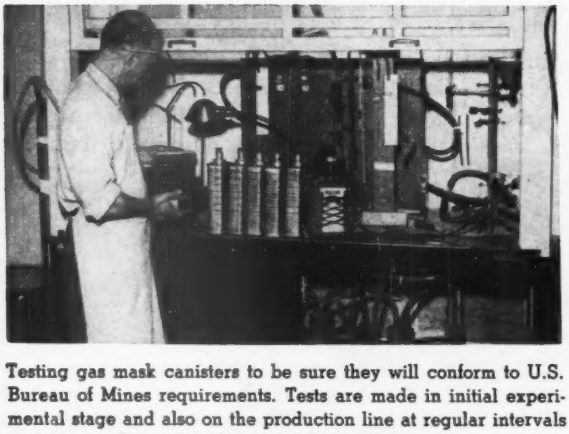

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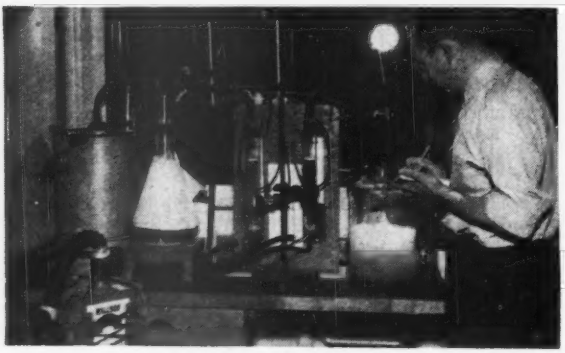

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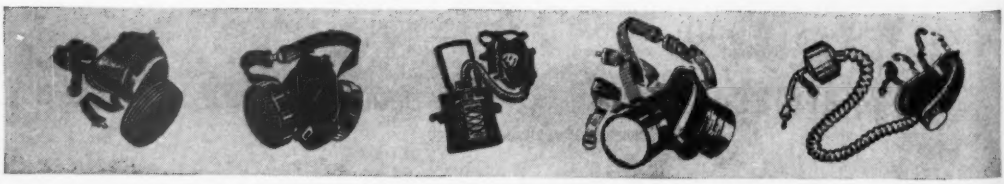

A Noise Survey of Manufacturing Industries

HENRY B. KARPLUS and GEORGE L. BONVALLET, Acoustics Research Group
Armour Research Foundation of Illinois Institute of Technology, Chicago

Sound pressure levels of steady state noise conditions inside plants of various manufacturing industries were measured and analyzed in octave bands. Measurements were made where operating personnel were exposed to the noise. They were taken at about 600 locations in 40 different plants selected from a wide range of industries.

Both the total loudness and the highest octave band loudness for each set of measurements were computed, since these single number representations have a better correlation with undesirable features of noise than overall sound pressure levels.

Measurements are divided into those taken close to principal noise sources, called machine levels, and those further away, called area levels. Analysis shows that about 50% of the machine levels were between 90 and 100 db. with total loudnesses between 100 and 300 sones and those in the loudest octave band between 30 and 100 sones. Approximately 50% of the area levels were between 85 and 95 db. with total loudnesses between 50 and 200 sones and those in the loudest octave band between 20 and 50 sones.

A chart is given showing the approximate relation between overall level and total loudness. The loudness corresponding to a given overall level varies over a range of approximately two to one.

Noise levels are further analyzed according to the industry in which they were found. The noisiest machines were found in all industries concerned with metals, followed by the lumber industry. The noisiest areas were found in some of the metals industries, followed by the textile and the chemical industries. The lowest levels were found in the apparel industry. Noise levels of a few widely used tools are also shown. The loudest operations were chipping and riveting, especially when the work consisted of large metal plates.

A tabulation of the original data, showing overall levels, octave band levels, and loudnesses, is appended.

I. Introduction

RECENT interest in the effects of noise environment on hearing, speech communication, and work performance[1,2,3] has created a need for definitive data on noise conditions in American industry. Until recently, large variations in instrumentation and measurement techniques have existed which made comparison of the limited published data difficult or impossible. In the survey described in this paper, measurements were made in typical factories of most industrial categories. This article presents the data obtained, as well as an analysis of the survey from which some significant generalizations can be drawn.

II. Scope of the Survey

AN ATTEMPT has been made in this survey to study the noise conditions existing in a wide range of industries. Visits were made to 40 plants of widely different manufacturing industries. Measurements were made at about 600 different locations in the

buildings of these plants, wherever operators were exposed to noise.

A. Selection of Factories and Measuring Locations:

As a guide for facilitating the selection of industries, use was made of the section "Manufacturing Industries" of the "Standard Industrial Classification Manual" issued by the U.S. Department of Commerce. This classification was modified somewhat for the analysis of the measurements in this survey. The classification used in this article, the types of plants visited, and the number of measurements made in each industry are shown in Table I. In some instances, different shops in the same plant were considered part of different industries. For example, the measurements taken in a department making small molded plastic components were classed with plastic products in the chemical industry and not with the machinery industry, where other departments of this plant were placed.

Most of the measurements here presented were taken specifically for this survey. In a few instances data from other sources were added. Interest was focused on those industries suspected of having noise problems, and therefore proportionately more plants in the metal industries were visited. This results in relatively more intense noises being measured.

Excluded from this survey were those locations where noise is incidental and not due to the work in progress. Thus the noise levels of offices, drafting rooms or warehouses were not included. Measurements were also confined largely to levels inside buildings. Noise levels of aircraft, traffic, and other general outdoor noises were not included. The noise of aircraft engines was also considered outside the scope of this project because, in general, these are tested in enclosures and operators are not exposed to the noise.

The statistical analysis of the data presented in this article gives equal importance to each measurement. No attempt has been made to weight readings with respect to the importance of an industry, the number of men exposed to a given level or the length of exposure. Very little is known about the effects of noise of short duration. Fatigue, interference with speech, discomfort, or hearing loss may depend differently on the duration of a noise. When more information is available on such relationships, suitable weighting factors may be applied to these data. For this purpose, all the sound pressure levels and loudnesses have been tabulated in the appendix. It is expected, however, that the general conclusions would not be changed significantly.

Table I.
Classification of Industries

	Industry	Number of Measurements Machines	Areas
a.	Food and Kindred Products	10	12
	Meat Packing		
	Candy Making		
b.	Textile Mill Products	18	15
	Spinning Mill		
	Weaving Mill		
c.	Apparel	5	3
	Men's Work Clothes		
d.	Lumber and Products	27	15
	Millwork		
	Lumber Mill of Paper Manufacturer		
	Furniture (two plants)		
e.	Paper, Printing, and Publishing	39	31
	Paper Manufacture (two plants)		
	Cardboard and Carton Making		
	Publishing and Printing Newspaper		
f.	Chemicals	21	21
	Heavy Chemicals		
	Paint		
	Plastic Products		
	Tire Making		
	Petroleum		
g.	Leather	13	23
	Finished Leather		
h.	Stone, Clay, and Glass	17	15
	Soft Stone Cutting		
	Tile		
	Glass Containers (two plants)		
	Concrete Aggregate		
i.	Primary Metal Industry	37	30
	Steel Foundry (three plants)		
	Steel Mill		
	Brass Foundry		
j.	Fabricated Metal Products	81	58
	Wire and Products		
	Small Tools (two plants)		
	Screw Machine Products		
	Steel Pipe		
	Machine Shops (in other groups)		
k.	Machinery	29	25
	Steel Plate and Boiler Making		
	Heavy Power Machinery		
	Internal Combustion Engines (two plants)		
	Earth Moving Machines		
	Electrical Appliances		
l.	Aircraft	12	26
	Aircraft Manufacturers (three plants)		

B. Measurements:

1. *Sound Pressure Levels:* Measurements of industrial noises were made with standard sound level meters and octave band

analyzers. Overall and octave band sound pressure levels were measured in decibels above the standard 0.0002 dyne per sq. cm. The overall level has been widely used in the past but is not adequate to describe a noise. Some measure of the contribution of different frequencies to the total noise is necessary. Since the noises encountered rarely contain high level pure tones, octave band analysis is suitable. All instruments used in the survey were calibrated in a random noise field by comparison with a laboratory standard. These techniques yield octave band sound pressure levels which may be relied upon to ± 3 db. Further details on methods of measurement may be found in an earlier article in this journal.[4]

2. *Machine and Area Levels:* Data are further subdivided into types of locations. Those taken close to the principal noise sources within two to five feet from a machine and in the vicinity of the operator are called machine levels. Other measurements were taken in places where men worked at some distance from the chief sources of noise and several machines could generally be heard. These have been termed area levels.

No correction has been applied to machine levels for the additional background because the factor of interest is the total noise to which the operator is exposed. In most cases, there was no significant contribution by the background except in two or three lower frequency octave bands. Where a machine did not stand out significantly above the background, it was considered to be too low to be measured and measurements of such a machine were considered area levels.

Where area levels were as high as machine levels because many similar large machines were operating quite close together, both machine and area levels are reported even though they are practically identical. The best examples of this were weaving sheds.

3. *Steady-State, Varying, and Transient Noises:* Commercially available sound measuring equipment is convenient for the study of steady noises. The precision of the meter is not the limiting factor and is quite satisfactory, because few noise levels remain the same from hour to hour or day to day. Many machines produce noises which change somewhat with the phase of the operation. With the slow response setting of the meter, some noises were found to vary a negligible amount from the values reported, while in some cases deviations as great as ± 10 db. were observed. Variations of over 10 db. can be expected with different operations or when performing the same operation on different pieces of work. For example, chipping or grinding small castings is much less noisy than similar operation on large thin plates.

Rapidly varying noises like sharp intense impacts are not readily measured with standard sound level meters.[4,5] Because of its inertia, the needle of the indicating meter is unable to follow a very sharp peak and its maximum excursion depends on the attenuator setting. Of interest in impact noises are peak intensity and duration. Laboratory techniques are required to measure these. There is also no information available on the relatively undesirable effect of a transient noise of given peak value and duration compared with a steady noise. Again this may well differ according to whether fatigue, speech interference, or hearing damage is of interest. More fundamental research is required before transient and steady noises can be compared. In this analysis only steady-state noises are given. These include impact noises which last longer than about one-half second or repeat more frequently than approximately twice per second since sound level meters are satisfactory for these.

III. Analysis

THE OCTAVE band sound pressure levels read on the meter were corrected for known calibration errors and an overall level calculated.[4] This corresponds to the overall level which would be measured on a meter with the weighting switch in the "flat" or "C" position. From the corrected octave band levels, corresponding loudnesses in sones were obtained.[4,7] This conversion to loudness[6] takes into account the response of the average human ear to sounds of different frequencies. Accordingly, more emphasis is given to the high frequency bands.

By summing the loudnesses in sones in each octave band, a total loudness is obtained. This calculated total loudness correlates well with subjective estimates of relative loud-

ness and is a better single number description of a noise than the overall level. The unit of loudness used here, the sone, unlike the decibel, is an arithmetic unit. Thus a loudness of 20 sones is twice as loud as one of 10 sones. This arithmetic scale has been found to be particularly easily understood by laymen.

Some of the undesirable effects of noise, such as deafening, appear to correlate with the level in narrow critical bands.[8,9,10,11] Consequently, the greatest loudness in any one octave band has also been given.

Reproduced in the appendix are all the measured octave band sound pressure levels, overall sound pressure levels, total loudnesses, and the loudnesses in the loudest band. In the following paragraphs, these values have been examined according to the relative number of times certain levels and loudnesses were encountered in this survey and how they were distributed among the various industries and among widely used tools.

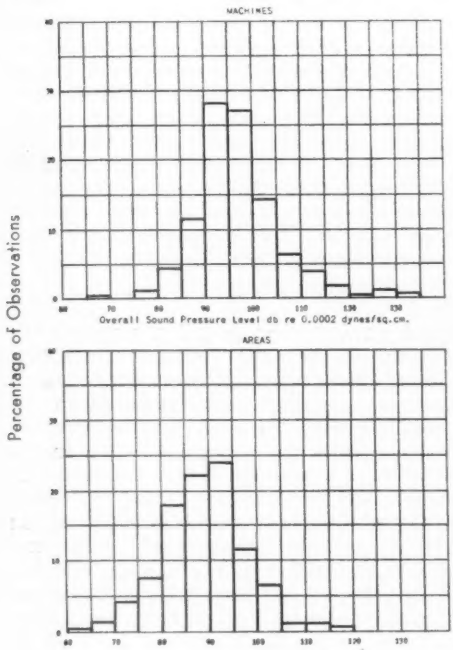

Fig. 1.
Distribution of overall sound pressure levels measured in industrial plants.

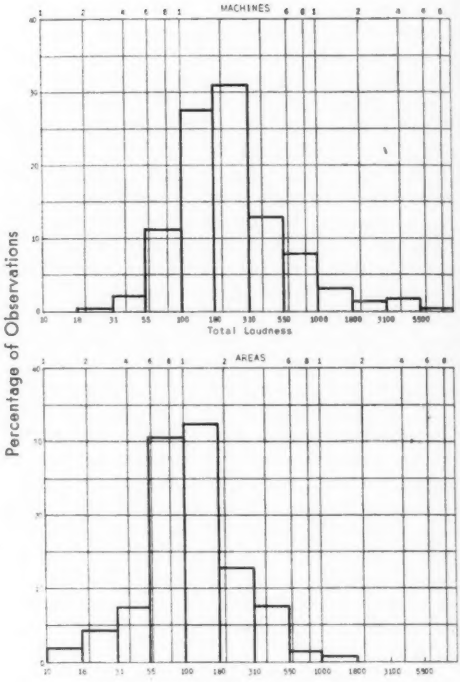

Fig. 2.
Distribution of total loudness.

A. Distribution of Noises in Industrial Plants:

The distribution of all the overall levels, total loudnesses, and loudnesses in the loudest band encountered in this survey are shown in Figs. 1, 2, and 3. Machine and area levels are treated separately.

Inspection of these curves shows immediately that more than 50% of the machines measured produced overall noise levels between 90 and 100 db., total loudnesses between 100 and 300 sones, and loudnesses in the loudest band between 30 and 100 sones. Furthermore, very few machines (less than 6%) could be measured with overall levels less than 85 db., total loudnesses less than 50 sones, and loudnesses in the loudest band less than 20 sones. It should not be concluded that there are no machines quieter than these, but that machines producing noise levels lower than these figures were rarely noticed by plant personnel and are considered by them to be relatively

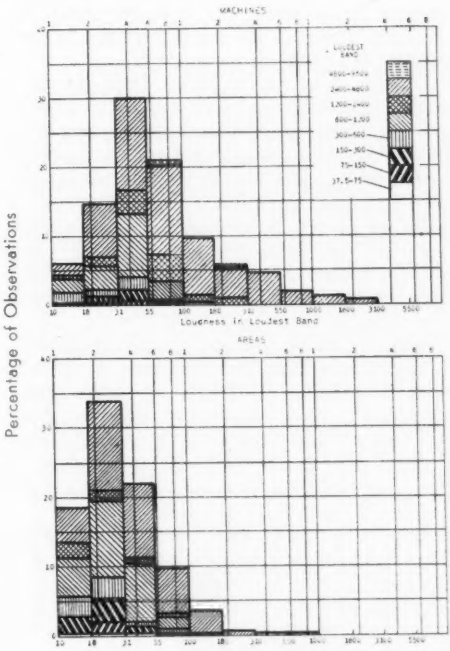

Fig. 3.
Distribution of loudness in loudest band.

quiet in the usual factory background.

In general working areas, about 50% of the measurements showed levels between 85 and 95 db., total loudnesses between 50 and 200 sones, and loudnesses in the loudest band between 20 and 50 sones.

In addition, Fig. 3 shows by means of shaded areas the distribution of octave bands in which maximum loudness occurs. For example, Fig. 3-A shows that for machine noises having a loudness in the loudest band from 31 to 55 sones, the loudest band is in most cases the 2400-4800 cps. band. It is immediately apparent that the maximum loudness often occurs in the low

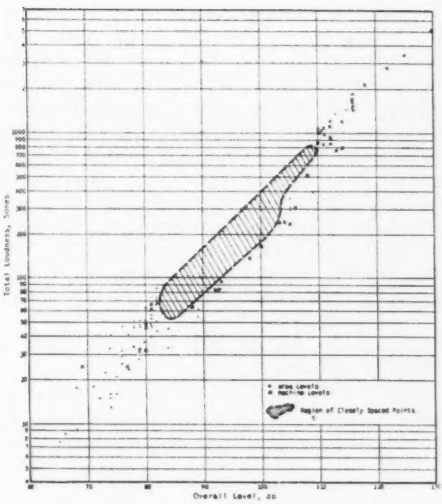

Fig. 4.
Relation between overall level and total loudness.

frequency bands when the loudness is low. For the louder noises, the fraction of measurements in which the loudest band is the 2400-4800 cps. band increases. Above 310 sones for machine levels and 180 sones for area levels, the loudest band was invariably the 2400-4800 cps. band.

The observations are summarized in a slightly different manner in Table II, where the median values, limits, and quartile deviations are shown. The lower limit gives lowest values observed. The lower quartile deviation is the value below which 25% of the observations were found, the median is the value below which 50% of the observations were found, the upper quartile 75%, and the upper limit gives the highest value observed. The extreme limits should not be interpreted too rigidly, since, undoubtedly, values outside this region can be found.

TABLE II.
LEVELS AND LOUDNESSES

		Machines			Areas		
Boundaries	Percent	Overall Level db.	Total Loudness Sones	Loudest Band Sones	Overall Levels db.	Total Loudness Sones	Loudest Band Sones
Lower Limit	0	66	4	1	60	2	1
Lower Quartile	25	92	130	31	84	65	15
Median	50	97	200	50	89	110	25
Upper Quartile	75	102	350	100	94	170	45
Upper Limit	100	133	6000	1700	120	1700	500

The relationship between overall level and total loudness for industrial noises has been plotted in Fig. 4. About 85% of the measurements are located in the shaded region. The other points show individual readings. From this chart the range of loudness likely to be encountered if only an overall level is known can be immediately read off on the ordinate. The range of loudness associated with a given overall sound pressure level is greater than 2 to 1. For example, if the overall is known to be 100 db., a loudness between 180 and 400 sones is to be expected.

B. Overall and Octave Band Levels in Individual Industries:

The limits, quartile deviations, and medians of overall and octave band levels of individual industries are shown graphically in Figs. 5-16. More detailed distributions for three selected octave bands (150-300 cps., 600-1200 cps., and 2400-4800 cps.) are shown in Figs. 17, 18, and 19. These bands were chosen as typical for the low, middle, and high frequencies.

The spectra shown in Figs. 5-16 are all composite. The limits, medians, and deviations apply in each case to all the measurements taken in the particular octave band. Thus no machine had a spectrum exactly like any of the curves shown. None was as high as the upper limit in all octave bands.

The distributions in Figs. 17-19 show the percentage of the locations found having a level lower than that shown on the ordinate. It can be seen on these curves whether most measurements were close in value (nearly horizontal line) or whether wide variations were encountered (steeply inclined line). It also becomes apparent where limits were due to one or two isolated readings (steep slope near the 0 or 100% ordinate) and where many readings close to the limit were found.

The following observations may be made from a study of Figs. 5-19:

(1) Area levels are lower than machine levels. This is particular true for the aircraft industry. Here a few noisy operations are scattered at great distances in large plants so that area levels are quite low. In this instance, most of the area levels were taken in a different plant from the machine levels and only twelve machine levels were taken altogether. This is not a sufficient sample from which to conclude that the machine levels in this industry are in general higher than in any other.

Fairly large differences between area levels and machine levels in the lumber and products industry may be explained by the fact that in most woodwork shops it is usual to find a large number of machines which are intermittently used, so that at any instant not many machines are operating. Consequently, the general area levels in this industry are lower in spite of the fact that machine levels are second only to the metal industries.

The chemical and the textile industries, however, show machine and area levels very close together. Conditions in these industries are in most cases very different from the aircraft industries. In these industries, it is usual to find many large machines very close together so that machine and area levels are frequently the same.

(2) High frequencies are less intense than low frequencies in area levels. For machine levels, a similar observation is found to hold for all but the textile industry and the industries concerned with work on metal.

(3) The difference between area and machine levels is greater at high frequencies than at low frequencies. This can be seen most clearly by comparing levels on Fig. 17 and Fig. 19. The high frequencies fall off more with distance.

Several factors contribute to this effect. High frequencies are usually radiated by small components of a machine, whereas low frequencies are effectively radiated by large surfaces. Very close to a noise radiator the intensity depends mainly on the amplitude of vibration of the source, whereas the general area level is a function of the total energy radiated and hence depends both on vibration amplitude and the radiating surface area. Consequently, the intense high frequency noises from small sources are concentrated near them whereas the low frequencies radiated by the larger sources are more uniformly distributed throughout the enclosed working area.

The general area levels are also reduced by absorption of sound. This takes place in the air and to some extent at room surfaces, even though they are not acoustically treated. High frequencies are diffused and ab-

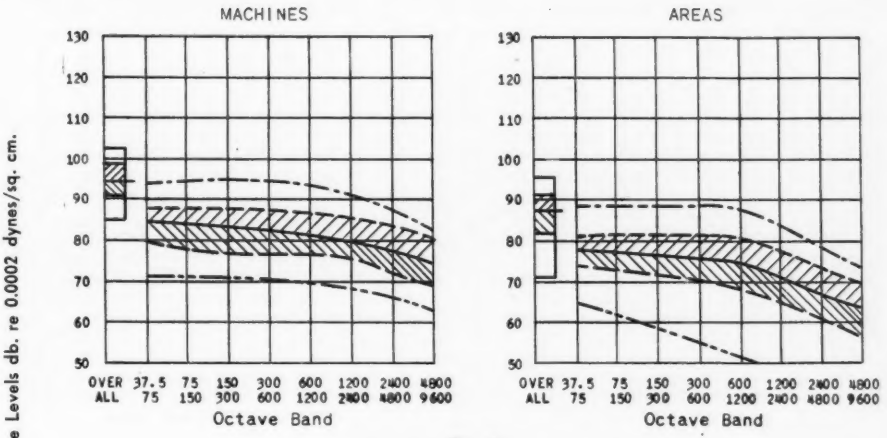

Fig. 5.
Sound pressure levels in the food industry.

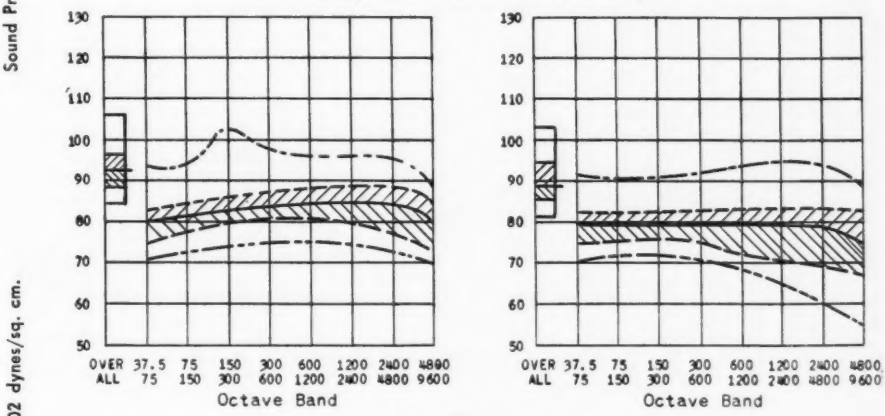

Fig. 6.
Sound pressure levels in the textile industry.

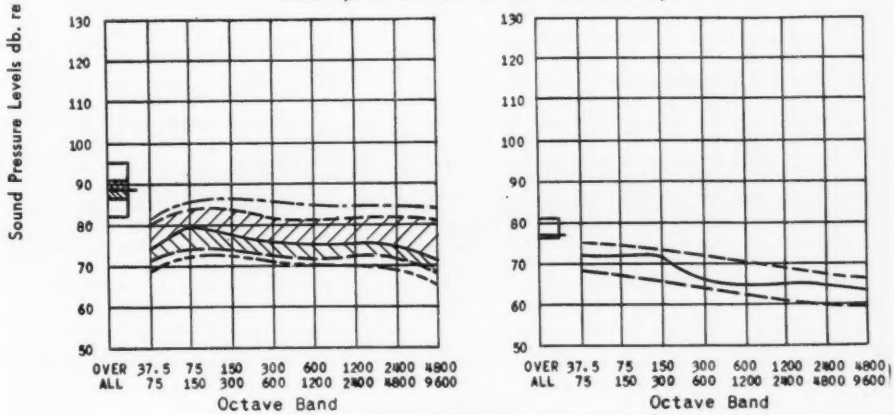

Fig. 7.
Sound pressure levels in the apparel industry.

Upper Limit
Upper Quartile Deviation
Median
Lower Quartile Deviation
Lower Limit

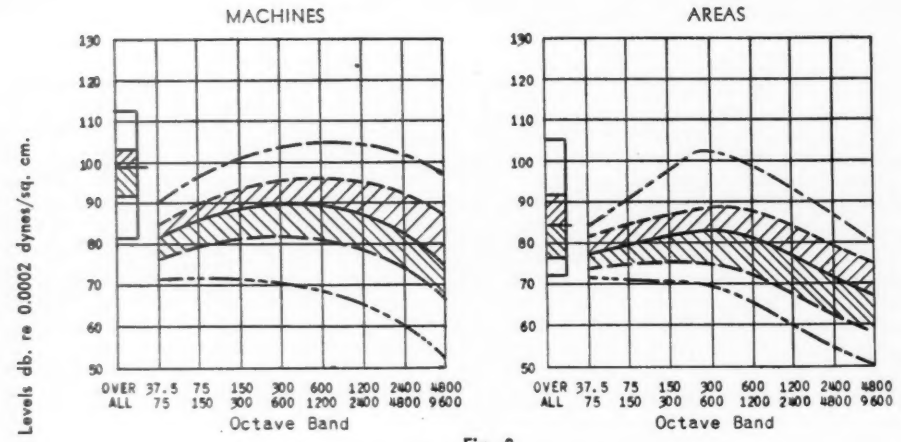

Fig. 8.
Sound pressure levels in the lumber and products industry.

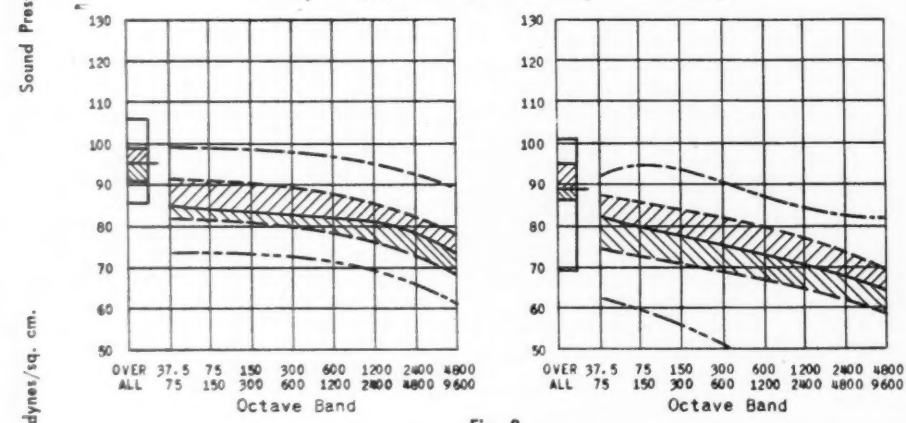

Fig. 9.
Sound pressure levels in the paper, printing, and publishing industries.

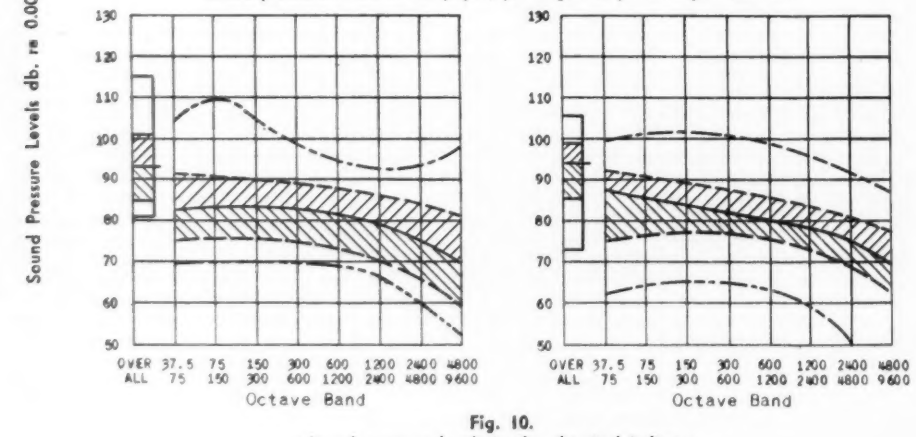

Fig. 10.
Sound pressure levels in the chemical industry.

Upper Limit
Upper Quartile Deviation
Median
Lower Quartile Deviation
Lower Limit

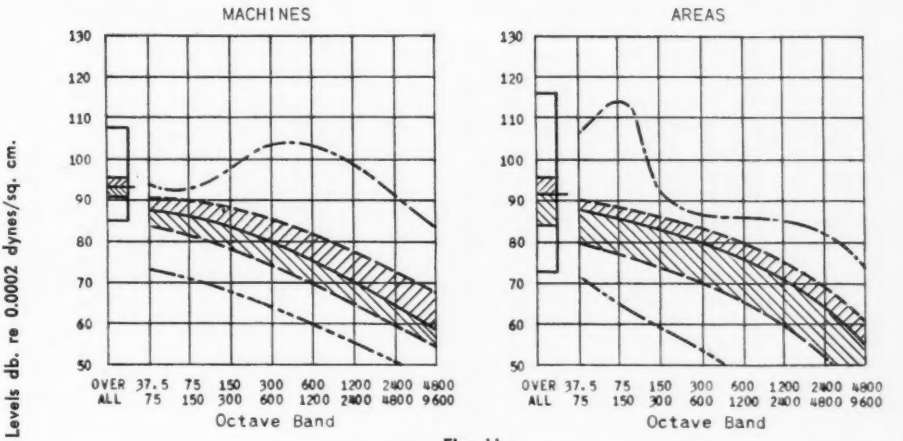

Fig. 11.
Sound pressure levels in the leather industry.

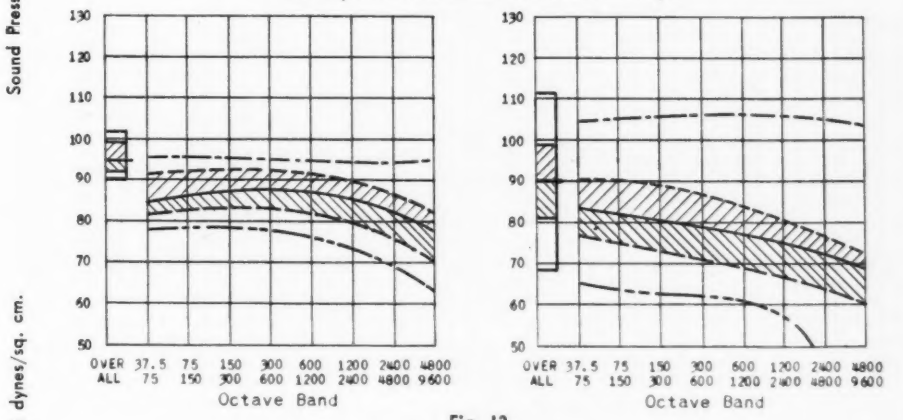

Fig. 12.
Sound pressure levels in the stone, clay, glass industries.

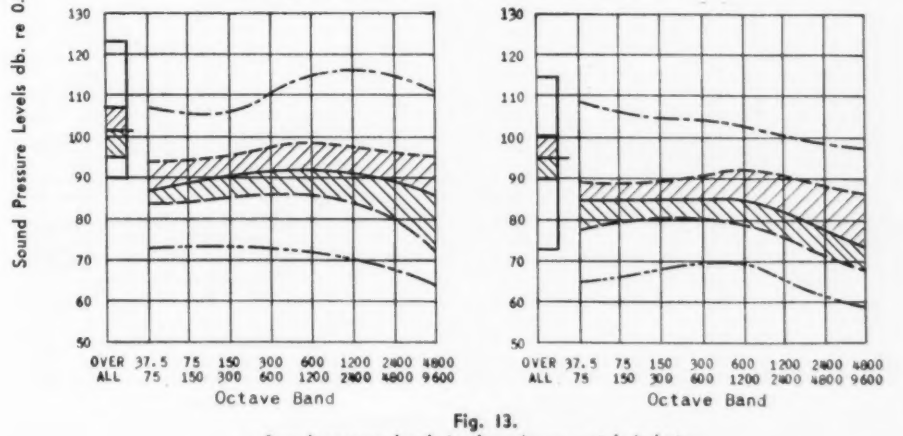

Fig. 13.
Sound pressure levels in the primary metals industry.

Upper Limit
Upper Quartile Deviation
Median
Lower Quartile Deviation
Lower Limit

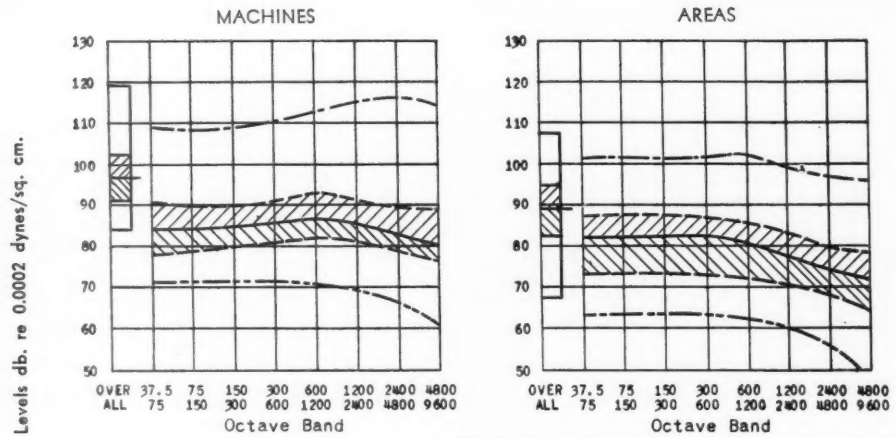

Fig. 14.
Sound pressure levels in the fabricated metal products industry.

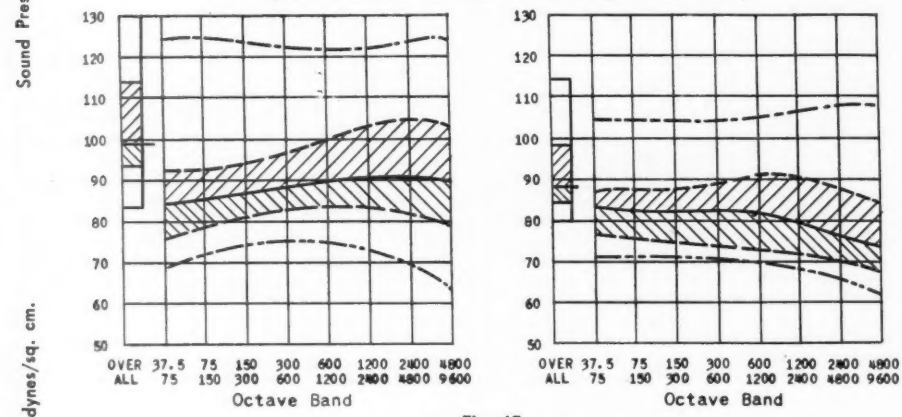

Fig. 15.
Sound pressure levels in the machinery industry.

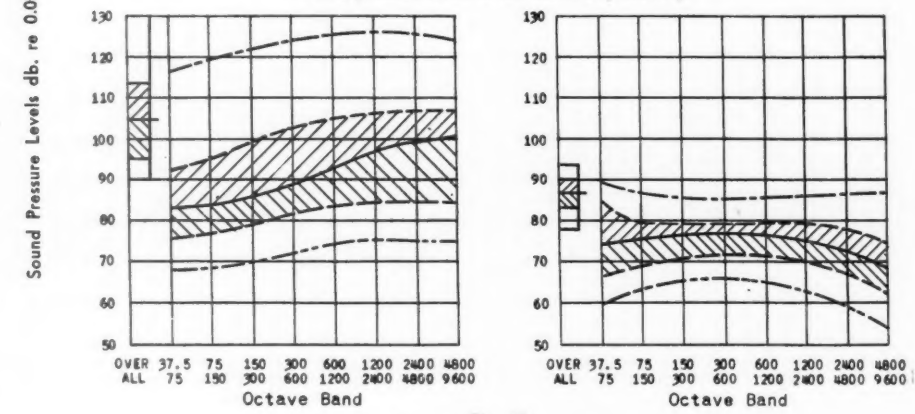

Fig. 16.
Sound pressure levels in the aircraft industry.

Upper Limit
Upper Quartile Deviation
Median
Lower Quartile Deviation
Lower Limit

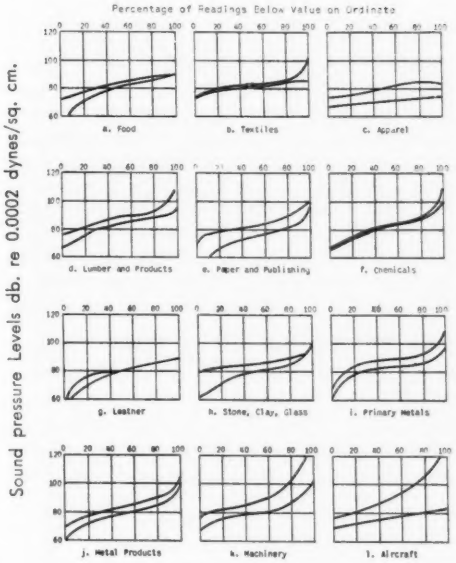

Fig. 17.
Distribution of sound pressure levels in the 150-300 cps. octave band.

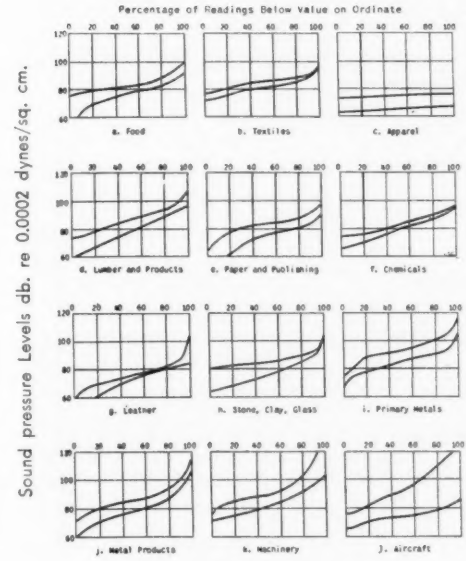

Fig. 18.
Distribution of sound pressure levels in the 600-1200 cps. octave band.

sorbed better than low frequencies, contributing further to the same effect. In some plants, large quantities of materials which absorb sound were found. Examples of these were large piles of corrugated cardboard for making boxes, or exposed cloth in the apparel industry.

(4) The curves of Figs. 17-19 indicate the range of observed values. The steep slopes near the 100% lines indicate that the upper limit of stone, clay, and glass industries shown in Fig. 12 were due to very few observations. These were near a very large machine making glass jars. Relatively larger numbers of observations close to the upper limit are shown by less steeply sloping lines near the limit. This condition is seen somewhat more often in the low frequency band shown in Fig. 17.

It may be well to point out again that not much significance is to be attached to the lower limit of machine levels; machines with less noise exist but could not be measured.

C. LOUDNESSES IN INDIVIDUAL INDUSTRIES: The loudnesses found in individual industries are plotted against the percentage of

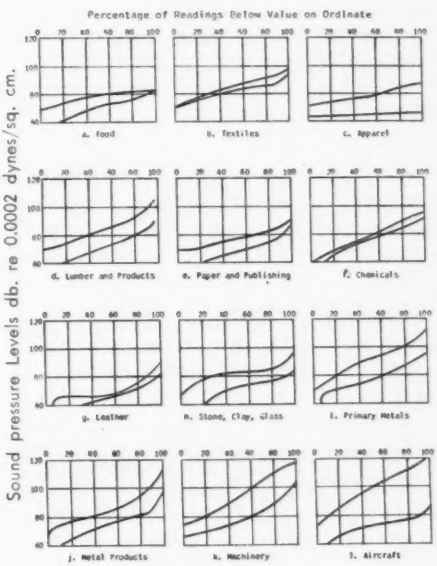

Fig. 19.
Distribution of sound pressure levels in the 2400-4800 cps. octave band.

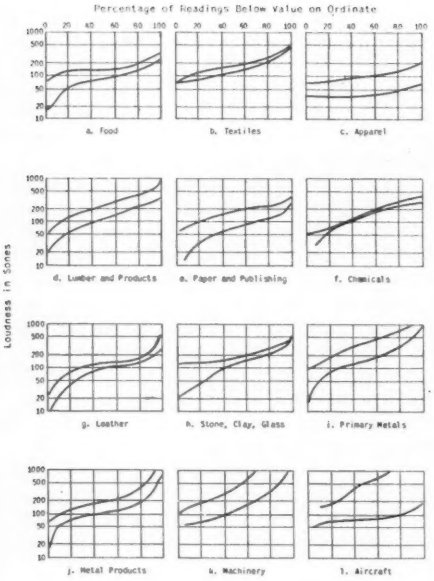

Fig. 20.
Distribution of total loudnesses.

measurements falling below this loudness in Figs. 20 and 21. Fig. 20 shows total loudnesses, and Fig. 21, loudnesses in the loudest band.

The curves generally follow a pattern similar to the distribution curves of octave band sound pressure levels, and especially to those for the 2400-4800 cps. octave band, as this is the most important one for determining loudness, particularly at the higher levels. As before, the metal industries are found to have the loudest machines with the lumber and products industry coming next. Relatively loud areas are found in the machinery, the primary metals, the textile, and the chemical industry.

D. SOUND PRESSURE LEVELS OF INDIVIDUAL MACHINES:

The octave band sound pressure levels of a few widely used machines are given in Figs. 22 to 33. They are presented approximately in order of decreasing loudness. The lowest, median, and highest levels observed are shown. All of the machines shown have sufficient uniformity that these three values are an adequate description.

The loudest operations encountered were chipping and riveting on large steel tanks and aircraft assembly, shown in Fig. 22. These have been separated from similar operations on smaller or more massive pieces, like small castings or concrete, which have been grouped with other pneumatic power tools such as drills and wrenches in Fig. 23. It is seen here, and it is important to note, that the noise is much more a function of the work than of the tool. A chipping hammer used on large steel plates causes these to vibrate with large amplitude and to radiate noise effectively. Massive castings or concrete structures are less easily excited and radiate less noise.

The spectra of saws, Fig. 24, include a metal friction saw, circular wood saws, and stone saws. The upper limit in the four high bands is due to the friction saw. A log slasher was slightly lower, and a circular wood saw measured close to 90 db. in every octave band; stone saws were about 85 db. The lower limit is a measurement of a small cut-off saw on ½ x ¼ inch molding.

Fig. 25 shows planers which include operations on wood and stone. A wide range of intensities was found. Planing a flat surface on fairly soft stone was the least noisy, whereas planing a concave stone surface

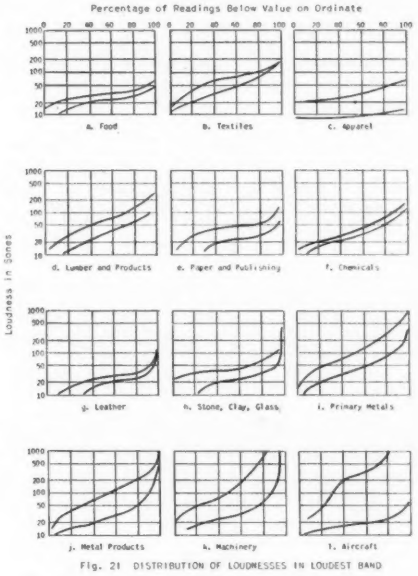

Fig. 21.
Distribution of loudnesses in loudest band.

SOUND PRESSURE LEVELS OF TYPICAL TOOLS

Sound Pressure Levels db. re 0.0002 dynes/sq. cm.

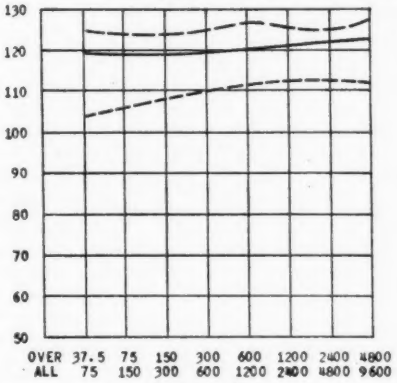

Fig. 22.
Riveting and chipping on large metal plates.

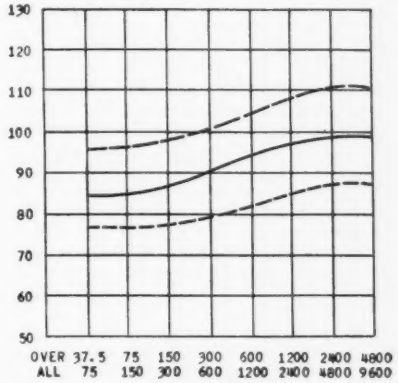

Fig. 23.
Riveting and chipping on small castings, and other pneumatic tools.

Sound Pressure Levels db. re 0.0002 dynes/sq. cm.

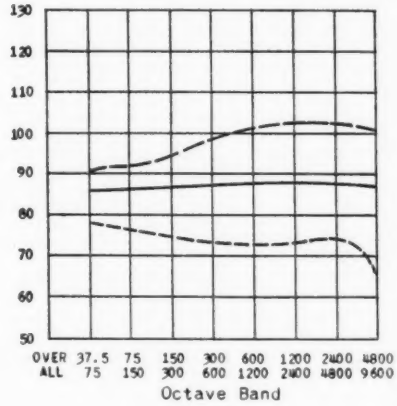

Fig. 24.
Saws

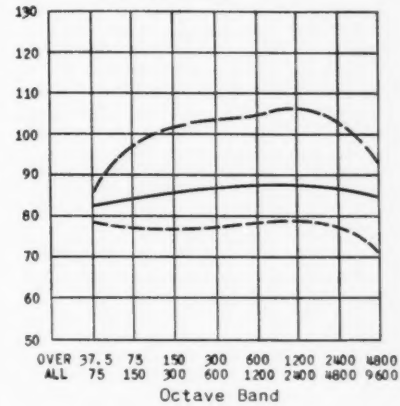

Fig. 25.
Planers

Sound Pressure Levels db. re 0.0002 dynes/sq. cm.

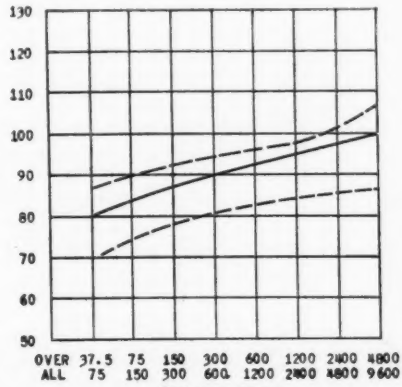

Fig. 26.
Tools with steam or air hiss.

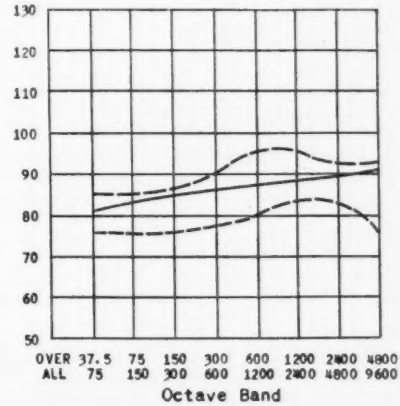

Fig. 27.
Tumblers

Upper Limit ——— Median _____ Lower Limit - - - - -

SOUND PRESSURE LEVELS OF TYPICAL TOOLS

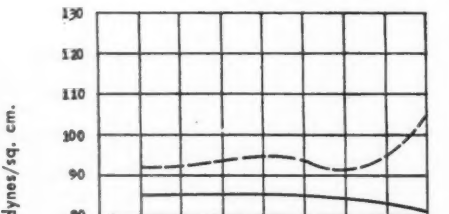

Fig. 28.
Grinders

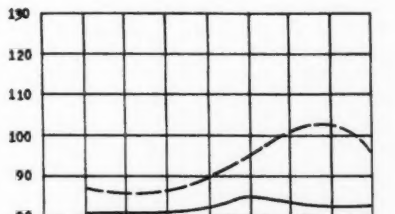

Fig. 29.
Welding equipment

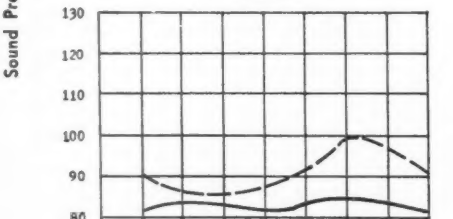

Fig. 30.
Lathes

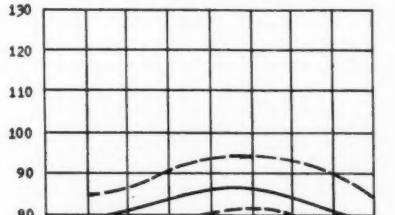

Fig. 31.
Drills, borers, milling machines.

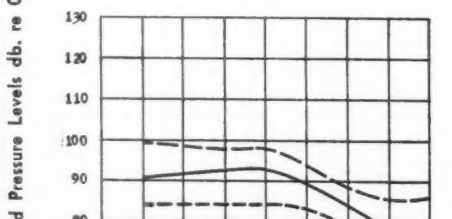

Fig. 32.
Furnaces

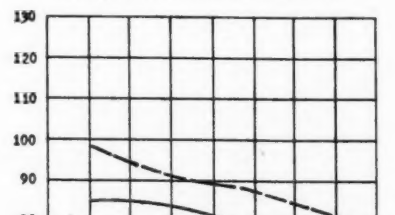

Fig. 33.
Mixers

Upper Limit ——— Median _____ Lower Limit — — —

was fairly close to the upper limit. Finish planing pine was close to the lower limit, whereas the normal planing operations of making a deep cut on hardwood were found close to the upper limit.

Steam and air hiss, as encountered in many operations, have upsloping spectra, as shown in Fig. 26. Upsloping spectra were also found in tumblers, Fig. 27, in which small castings are knocked together in a deburring operation. Grinding, welding, and machine shop operations like lathe work, drilling, milling, and boring are in general less noisy, as shown in Figs. 29-31. The high level shown in Fig. 30 was a screech produced periodically by a lathe taking a very thick cut.

Furnaces and mixers, Figs. 32 and 33, are examples of machines having downsloping spectra. Furnaces have fairly high overall levels, but are not usually judged to be very loud because of the low intensity in the high frequency region. Mixers were the least noisy class of machine listed here.

IV. Summary

STEADY-STATE noise levels, as they affect workers in manufacturing industries, were measured and analyzed in octave bands. Measurements made close to the principal noise sources were studied separately from those in general areas. The latter, though less intense, generally affect a larger number of workers.

Wide variations of noise levels were found. Analysis by industry showed that the noisiest machines were found to be those working on metal, followed by those working on wood. The noisiest areas were found in the machinery, the chemical, the stone, clay and glass, and the textile industries. Large differences between the machine and area levels were found in the aircraft, the machinery, and the lumber and products industries where machines were widely spaced or run intermittently, or where large amounts of material with sound absorbing properties were present. Little difference between the machine and area levels was found where many large machines were close together, as in the textile, the chemical or the leather industries.

The analysis showed that about 50% of the machine levels were between 90 and 100 db., with total loudnesses between 100 and 300 sones, and loudnesses in the loudest band between 30 and 100 sones. In general working areas, about 50% of the measurements were between 85 and 95 db. overall, total loudnesses between 50 and 200 sones, and loudnesses in the loudest band between 20 and 50 sones.

As a measure of an average or a most frequently occurring value, the medians have been computed. These varied for machines from 88 db. overall with a loudness of 100 sones in the apparel industry, to 103 db. with 500 sones in the aircraft industry. Medians for areas varied from 77 db. with a loudness of 30 sones in the apparel industry, to 93 db. with 170 sones in the chemical and the stone, clay, and glass industries.

In analyzing the data according to the type of machine or operation, most variations were relatively small. Many similar operations can be associated with typical noise spectra, and in several instances shown they did not differ by more than 8 db. from the median levels in octave bands. The most intense noises were found to be produced by pneumatic riveting and chipping, especially if the work consisted of large metal plates. The noise of these operations, as well as many others, depends not only on the machine but also on the work. Other factors affecting noise of machines are design, installation, and age.

An approximate relation between loudness and overall level has been given. These data indicate that if the overall noise level is known, the loudness can be estimated approximately to within limits of two to one. This corresponds to a change of level of about 8 db. For loud noises, the greatest contribution to the loudness was in the 2400-4800 cps. band in most cases.

V. Conclusion

A SURVEY of steady-state noise affecting workers in manufacturing industries has been made. Representative samples of a wide range of industries have been included. In a few industries more samples might have been considered desirable, but in the metal working industries, having the most severe noise problems, extensive data have been collected. The relative noise levels in various industries and for various operations have been discussed. These data should be of value in determining remedial meas-

ures. General area levels are less noisy than machine levels, so that the majority of workers are not exposed to very high levels.

It has been pointed out that more precise weighting would require consideration of the number of operators and duration of exposure. Further investigation of effects on exposure time and recovery period is needed.

VI. Acknowledgment

THE PROGRAM of which this is a part has been under the direction of DR. H. C. HARDY, Assistant Chairman, Physics Research Department, and D. B. CALLAWAY, Supervisor, Sound and Vibration Control Section. The cooperation of the Foundation Acoustics staff is acknowledged, particularly that of F. G. Tyzzer, Senior Physicist, who assisted in the analysis and interpretation of the data.

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Appendix

In the tables which follow, overall and octave band sound pressure levels as well as total loudnesses in sones and the loudness in the loudest band in sones are tabulated as determined from the field survey. Data are subdivided into types of locations. Those taken close to the principal noise sources within two to five feet from a machine and in the vicinity of the operator are called machine levels. Other measurements were taken in places where men worked at some distance from the chief sources of noise and several machines could generally be heard. These have been termed area levels.

It is emphasized that these data are indicative only and that variations in identical operations even in machines of similar or identical make may be large. Only in cases where measurements of the same type of operation were available, can statistical significance be attached to the data.

TYPICAL SOUND PRESSURE LEVELS AND LOUDNESSES IN INDUSTRIAL PLANTS

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db.								TOTAL LOUDNESS SONES	LOUDEST BAND SONES
			37.5 75	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600		
a	FOOD MACHINES											
1	Chop Cut Machine, Meat	100	98	91	90	89	90	84	80	84	230	44
2	Canning Machine, Meat	92	76	72	75	79	90	85	77	74	150	44
3	Vacuum Mixer, Meat	100	94	90	82	94	96	86	70	77	230	62
4	Sausage Machine	83	70	73	72	76	78	74	70	68	76	18
5	Bacon Presser	88	82	80	77	80	82	81	81	74	140	36
6	Ham Can Cleaner	90	85	86	82	77	78	77	78	79	130	28
7	Fudge Molding Machine	95	92	88	87	84	83	81	78	71	170	28
8	Candy Wrapper	100	100	84	75	76	79	80	82	76	160	40
9	Peanut Blanching Machine	95	92	87	89	83	83	81	81	75	180	37
10	Covering Candy with Nuts	92	86	86	85	84	81	79	77	73	150	26

TYPICAL SOUND PRESSURE LEVELS AND LOUDNESSES IN INDUSTRIAL PLANTS†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db. 37.5–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800	4800–9600	TOTAL LOUDNESS SONES	LOUDEST BAND SONES
	FOOD (Cont'd)											
	AREAS											
1	Sausage Kitchen	96	89	91	87	87	88	86	80	77	210	43
2	Meat Preparation Room	96	85	86	91	91	88	80	76	73	180	38
3	Bacon Slicing Room	83	78	74	74	75	76	72	70	70	76	16
4	Canning Area	74	66	66	66	66	66	66	66	66	41	10
5	Sausage Making Room	72	70	67	56	49	52	51	47	47	15	2.6
6	Chocolate Coating	91	82	84	84	83	82	79	73	64	130	24
7	Candy Mixing	87	83	79	83	73	70	63	62	55	67	17
8	Packing Department	82	79	74	71	69	73	72	74	68	72	20
9	Blanching and Roasting	92	89	84	86	82	80	80	73	70	140	26
10	Chocolate Melter and Mixing Pit	89	84	81	80	82	83	66	59	52	92	26
11	X-Ray Room	84	82	77	74	72	71	66	65	59	62	11
12	Covering Candy with Nuts	90	86	83	81	81	79	75	75	71	120	22
b	TEXTILES											
	MACHINES*											
1	Reducing Machines, 72 Spindle	93	76	78	80	81	88	85	85	78	180	55
2	Reducing Machine, 60 Spindle	95	78	82	80	84	87	92	90	85	180	89
3	Reducer Transfer Machine	89	76	78	76	78	82	85	83	78	150	44
4	Speeder Machine, Yarn Processing	97	76	79	84	85	89	93	93	85	290	110
5	Combing Machines	95	84	84	85	84	84	86	88	84	230	80
6	Pin Drafters	92	77	77	78	79	85	85	87	85	190	66
7	Preparers	97	81	84	87	90	90	92	91	85	300	99
8	Finishers	98	82	85	85	88	90	92	94	89	320	110
9	Spinning Frames	86	80	81	80	75	77	75	73	68	97	18
10	Twisters, Universal	87	81	83	82	79	79	78	78	74	120	28
11	Twisters, Cap Type	91	84	86	84	80	84	84	84	75	180	49
12	Ring Spinning	89	76	78	86	84	82	78	75	74	130	24
13	Carding Area	86	80	80	80	77	77	75	75	70	99	23
14	Combing Machines	86	77	74	75	76	80	81	81	78	290	99
15	Preparers	92	75	76	81	83	86	86	85	80	190	55
16	Woven Material Washing Area	103	80	84	103	93	85	75	70	66	190	70
17	Drawing Area	93	81	85	84	83	87	87	86	85	220	60
18	Weaving Shed	102	94	91	86	87	95	97	97	90	490	190
	AREAS*											
1	Combing Machines	95	84	84	85	84	84	86	88	84	230	80
2	Pin Drafters	92	77	77	78	79	85	85	87	85	190	66
3	Finishers	98	82	85	85	88	90	92	94	89	320	110
4	Spinning Frames	87	80	81	80	75	77	75	73	68	97	18
5	Ring Spinning	90	76	77	80	81	83	82	82	79	150	40
6	Reelers	82	75	74	74	72	74	73	73	64	87	19
7	Card Machines	86	80	78	78	75	75	76	76	73	100	25
8	Combing Machines	94	77	82	83	82	84	89	88	86	230	72
9	Dry Finish Area	87	79	84	80	78	75	73	66	56	85	15
10	Dye House Area, Noise of Preparer	85	79	75	76	75	76	77	76	72	94	24
11	Web Finish Area	87	79	81	78	78	82	74	66	57	92	24
12	Drawing Room	89	79	81	80	78	80	82	82	78	140	40
13	Spinning Machines	84	75	77	77	74	72	74	74	75	83	20
14	Storage Room, Machines on Floor above	95	92	90	85	81	85	77	69	62	150	30
15	Weaving Shed, Looms	101	92	90	85	86	94	96	96	89	450	170

**Levels in yarn processing areas are generally between machines, since this is the usual operator position. Many of the levels in this industry are typically area levels as well as machine levels and therefore are listed in the list of area levels*

†See introductory paragraph at the beginning of appendix.

Typical Sound Pressure Levels and Loudnesses in Industrial Plants†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db. 37.5–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800	4800–9600	TOTAL LOUDNESS SONES	LOUDEST BAND SONES
c	APPAREL MACHINES											
1	Sewing Machine, Men's Garments	87	78	85	78	76	73	75	75	70	97	22
2	Button Holer, Garments	81	72	75	75	73	76	76	76	68	87	24
3	Fabric Cutter, Garments	91	75	85	81	75	81	85	85	86	180	55
4	Fabric Cutter, Garments	89	71	83	73	73	75	75	81	82	110	37
5	Sewing Machine, Garments	85	77	77	78	76	79	73	71	71	88	19
	AREAS											
1	Sewing Machines, Wearing Apparel	77	72	73	68	63	62	65	65	60	40	9.5
2	Button Holers, Wearing Apparel	77	70	72	73	66	64	63	63	56	40	7.9
3	Sewing Machines, Wearing Apparel	81	73	75	75	72	67	67	66	66	56	10
d	LUMBER AND PRODUCTS MACHINES											
1	Wood Planer, ⅜″ Cut on 12″ x 16″ Pine Pieces	108	80	77	102	94	100	105	98	93	720	250
2	Circular Cut-off Saw, End Cut on 6″ x 2″ x 1″ Beech	106	83	80	82	88	89	87	104	102	720	400
3	Drum Barker, Tumbling of 2′ Long x 6″ Dia. Log Pieces	98	92	91	93	88	89	78	74	77	201	41
4	Slasher, Four 36″ Circ. Saws, 12″ Logs	99	90	90	88	91	96	88	89	92	340	80
5	Drum Sander, 36″, on Pine Millwork	92	84	87	83	86	81	77	70	66	130	27
6	Finishing Planer, 30″ on Pine Windows	90	84	83	82	85	84	80	79	77	150	31
7	Jointer, 16″ on Millwork	96	84	91	93	86	84	73	72	62	160	36
8	Drum Sander, 54″, Three 12″ Drums, Millwork	85	84	79	75	73	73	70	69	58	74	14
9	Shaper, Moulding Millwork	92	88	87	81	88	87	84	82	74	190	40
10	Double Surfacer, 30″ Rough Surfacing Pine	98	88	85	87	88	87	92	93	84	320	120
11	Cut-off Saw, 15″, 2″ x 4″ Pine	90	88	83	77	75	77	76	79	74	120	31
12	Planer, 30″, 4′ x 8″ x 2″, Oak Pieces	100	82	86	96	95	95	84	84	74	270	62
13	Sander, Three 14″ Drums, 10′ x 6″ Oak	90	83	82	83	82	83	77	76	72	130	26
14	Shaper, Pine Millwork	96	82	87	89	92	86	86	86	72	230	60
15	Sticker Moulder, Shaping Furniture Parts	101	85	89	88	91	96	97	92	84	400	120
16	Planer, Furniture Parts	112	84	88	104	102	107	107	98	100	940	310
17	Double-Ended Tenoner, Furn. Rails	99	81	89	96	88	84	89	89	85	280	80
18	Cut-off Saw, Comp. Air, Furn. Parts	107	85	84	88	101	94	100	99	100	660	240
19	Surfacer, 12″ x 6″ x 1″ Birch	104	85	86	96	96	101	95	95	85	490	150
20	Automatic Lathe, Birch Bed Posts	100	91	91	95	90	95	94	88	82	350	90
21	Jointer, Idling	99	80	86	98	92	80	76	74	68	170	51
22	Drum Sander, on Veneer Sheets, 8′ x 4′	98	85	86	90	92	95	85	84	78	250	62
23	Double Ended Tenoner, Furniture Components	96	78	86	92	92	84	78	90	74	240	89
24	Shaper, Furniture Components	87	78	79	82	76	76	79	79	73	110	30
25	Planer, Maple Furniture	103	78	81	96	91	99	98	95	85	480	150
26	Molder, Maple Furniture	101	76	83	88	97	96	94	92	85	380	110
27	Planer, Furniture Components, Hard Wood	101	82	87	88	92	95	95	93	90	390	120
	AREAS											
1	Mill Shop, Joiners, Planers, etc.	91	85	86	86	82	84	75	74	73	130	28
2	Carpenter Shop, Distant Noise Only	73	70	66	65	57	58	56	55	47	22	4
3	Log Sawing, Barking, Cutting Knots, etc.	99	90	93	91	89	95	81	76	72	230	62.3
4	Wood Finishing, Sanding, Planing, Jointing	85	84	75	74	74	71	69	67	57	67	12
5	Wood Finishing, Sanding, Planing, Jointing	83	82	75	73	70	65	60	56	52	45	8.5
6	Wood Finishing, Sanding, Planing, Jointing	87	82	77	83	78	77	70	66	52	84	17
7	Furniture Making, Planers, Jointers, Saws, etc.	101	82	86	95	96	95	92	86	78	320	72

†*See introductory paragraph at the beginning of appendix.*

TYPICAL SOUND PRESSURE LEVELS AND LOUDNESSES IN INDUSTRIAL PLANTS†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db. 37.5 75	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600	TOTAL LOUDNESS SONES	LOUDEST BAND SONES
	LUMBER & PRODUCTS—AREAS (Cont'd)											
8	Furniture Making, Planers, Jointers, Saws, etc.	94	79	85	91	86	84	83	81	73	180	37
9	Furniture Making, Lathes, Saws, etc.	103	80	82	90	103	89	83	81	73	290	80
10	Veneer Dept., Veneer Mach., Presses, Saws	81	76	77	72	71	66	65	64	54	49	9.2
11	Furniture Making, Planers, Shapers, Molders	97	78	86	92	92	84	78	90	74	240	89
12	Furniture Making, Planers, Shapers, Molders	84	75	78	80	75	71	69	68	62	71	14
13	Furniture Making, Planers, Shapers, Molders	94	78	80	88	88	89	78	74	70	150	41
14	Furniture Making, Planers, Shapers, Molders	91	78	80	84	82	85	83	80	75	150	34
15	Spraying Varnish, Air Exhaust, etc.	89	76	82	84	83	82	72	62	58	99	24
e	PAPER, PRINTING, AND PUBLISHING MACHINES											
1	Drum Barker, Tumbling Logs	98	92	91	93	88	89	78	74	77	200	41
2	Slasher, Four 36″ Dia. Saws, 50 Hp.	98	90	90	88	91	96	88	89	92	340	80
3	Wet Machine, Pulp Preparation	96	93	91	84	80	77	76	70	67	140	24
4	Stock Mixer, 300 Hp., Pulp Process	95	85	80	82	83	93	83	83	80	200	53
5	Paper Machine, Wet End, 400′ x 16′ x 12′	94	89	89	85	85	86	79	75	75	160	32
6	Calender, Clutch, and Gear Noise	97	84	94	88	85	91	87	82	83	230	47
7	Suction Pump, for Paper Machine	101	91	97	98	85	87	81	80	82	250	50
8	Printer-Slotter, Prints, Slots Cartons	98	90	91	89	92	92	92	88	80	300	75
9	Box Stitcher, Stitches Cartons	87	77	82	78	78	78	80	80	76	120	34
10	Folder, Automatic Taper (Cartons)	100	93	94	91	89	90	84	82	78	200	40
11	Folder, Automatic Taper (Cartons)	95	87	89	87	86	86	83	82	78	240	44
12	Corrugator, Double, Corrugated Cardboard	100	82	81	94	95	94	88	86	78	280	60
13	Corrugator, as 12 Cutting End	96	88	87	90	91	86	79	75	60	180	37
14	Corrugator, Single	89	80	81	83	82	77	71	71	70	100	21
15	Printer-Slotter, Prints, Slots Cartons	89	84	84	79	80	75	72	72	64	99	18
16	Trimmer Section, Pamphlet Stitcher	91	83	80	78	78	82	81	80	85	150	35
17	Folder, Large Sheet, Noise Due to Worn Parts	94	86	81	81	81	84	85	86	90	200	60
18	Folder, Large Sheet, Noise Due to Worn Parts	91	80	79	79	81	84	83	84	89	180	49
19	Shear, Idling, Noise Due to Worn Parts	103	88	86	82	85	92	97	86	89	320	120
20	Two-Color Press, 47″ x 71″	93	84	88	86	81	83	81	80	....	160	35
21	Two-Color Rotary Press, 45″ x 65″	92	86	88	84	82	80	76	76	80	140	25
22	Two-Color Press	92	83	83	84	83	83	81	80	85	170	35
23	Letter Press, Size 6/0	93	78	84	86	83	87	84	79	76	170	37
24	Four-Color Offset Photography Press	92	82	83	84	86	88	82	76	74	150	35
25	Ink Mill, Noise of Worn Parts	93	76	82	86	85	89	82	72	70	150	41
26	Cleaning Tank, Steam Noise	87	82	81	78	75	76	71	68	72	83	14
27	Printer-Slotter, Cardboard Boxes	99	90	91	89	92	92	92	88	80	300	75
28	Metal Stitcher	91	86	84	82	82	82	78	78	74	130	28
29	Combining Machine, Pasting Multi-Ply Sheets	92	85	86	86	83	86	83	73	76	160	32
30	Paper Machine, 300′ x 14′ x 12′	106	103	98	93	89	92	88	83	75	300	52
31	Paper Machine, 300′ x 14′ x 12′	97	95	91	82	81	81	80	79	77	160	30
32	Paper Machine, 300′ x 14′ x 12′	98	96	92	83	83	83	87	73	64	190	47
33	Pulp Grinder	105	102	95	91	95	96	94	90	78	420	90
34	Newspaper Press, Standard Type	102	94	99	94	94	90	84	82	75	280	45
35	Newspaper Press, Standard Type	103	95	101	96	94	89	87	84	77	310	51
36	Newspaper Press, Standard Type	102	94	98	94	92	87	80	76	68	230	42
37	Newsprint Rewinder	88	86	78	77	76	79	74	71	67	95	19
38	Linotype Machine	81	77	73	73	74	73	70	68	64	66	13
39	Air Ejector, Cleaning	83	78	71	71	70	67	68	76	74	60	24

†*See introductory paragraph at the beginning of appendix.*

Typical Sound Pressure Levels and Loudnesses in Industrial Plants†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db. 37.5–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800	4800–9600	TOTAL LOUDNESS SONES	LOUDEST BAND SONES
	PAPER, PRNTG. & PUBLISHING (Cont'd) AREAS											
1	Wet Machines, Paper Making	95	93	90	85	80	75	75	69	67	130	23
2	Beater Room, Pulping Machines	89	85	84	82	79	80	75	72	70	110	21
3	Paper Machine, 400′ x 16′ x 12′	94	89	89	85	85	86	79	75	75	160	32
4	Calenders	88	83	84	78	80	80	69	64	63	91	21
5	Paper Machine Auxiliary Equip., Pumps, etc.	96	88	93	90	85	88	77	75	72	170	29
6	Cardboard Box Folding and Taping	87	81	77	77	77	80	78	78	74	110	28
7	Corrugator	88	80	81	83	78	78	71	68	65	95	18
8	Folding Area, Paper Folders, Large Sheets	91	80	78	78	80	83	83	83	86	160	44
9	Cutting Area, Numerous Paper Shears	87	82	80	76	75	78	77	77	79	110	26
10	Pressroom, Two Color Printing	89	83	85	80	77	78	76	75	73	112	22
11	Offset Pressroom, Several Presses	71	69	62	58	55	57	55	52	51	18	3.7
12	Roto Press Room	68	65	60	60	56	54	55	55	52	18	4.3
13	Ink Room	87	76	80	79	79	79	75	72	70	97	19
14	Printing-Slotting Area	93	85	85	87	84	86	82	82	71	180	40
15	Metal Stitching	87	84	78	77	77	77	75	73	67	95	19
16	Shipping Room	76	75	62	60	59	61	60	59	45	26	5.8
17	Combining Area, Pasters, Mixers	93	85	86	86	83	86	83	73	76	160	33
18	Paper Machine, 300′ x 14′ x 12′	105	103	98	93	89	92	88	83	75	300	52
19	Paper Machine, 300′ x 14′ x 12′	97	95	91	82	81	81	80	79	77	160	31
20	Paper Machine, 300′ x 14′ x 12′	98	96	92	83	83	83	87	73	64	190	47
21	Beater Room, Pulping Machines	88	87	80	76	73	71	68	65	58	72	12
22	Proof Room, Noise of Message Conveyor Belt	75	74	66	62	61	59	52	48	40	21	4.3
23	Pressroom, Newspaper Presses	97	88	93	91	86	82	75	70	64	160	31
24	Paper Storage, Trucks, Conveyors	89	86	80	77	77	75	72	74	66	94	20
25	Mail Room, Paper Bundling Machines	84	79	79	71	76	69	64	66	64	61	10
26	Galley Room	83	78	77	77	68	67	67	66	60	57	11
27	Associated Press Room, Teletype Machines	77	74	71	69	60	59	52	49	46	24	4.3
28	Photography Department, Distant Noise	75	74	63	65	54	51	46	44	40	16	3.7
29	Stereotype Room, Working Printing Plates	92	85	89	81	80	75	76	69	58	110	21
30	Composing Room	81	77	73	71	72	67	65	62	56	47	9.9
31	Linotype Machines	81	78	74	72	71	69	67	67	62	56	11
f	CHEMICALS MACHINES											
1	Ink Mill, Noise of Worn Parts	93	76	82	86	85	89	82	72	70	150	41
2	Pigment Mills, Steel Ball Grinding	94	82	83	85	86	86	87	85	79	210	55
3	Pebble Mill	84	79	75	77	75	74	73	67	57	72	14
4	Mixer, Enamel Components	83	76	74	73	74	80	67	57	....	62	21
5	Drum Cleaning	85	74	77	80	76	74	75	74	65	93	22
6	Pigment Mill, Enamel Grinding	82	69	72	76	75	75	73	69	56	70	14
7	Five-Roll Mill	113	105	110	109	101	89	82	79	80	430	102
8	Hammermill	104	98	93	92	97	95	94	92	96	460	110
9	Boiler Room, Blower	100	89	91	98	92	87	84	85	78	260	55
10	Compounding Roll, Plastic Components	94	87	86	84	84	90	84	79	77	190	44
11	Ball Mill, Plastic Components	99	82	82	82	84	93	95	93	92	320	130
12	Fabric Coating, High Temperature Type	81	72	71	68	74	76	69	69	67	61	14
13	Fabric Coating, Low Temperature Type	85	75	75	74	73	80	80	74	61	93	26
14	Fabric Coating, Low Temperature Type	82	71	72	73	73	74	80	64	54	72	26
15	Rewind, Fabric Beaming	93	88	89	84	80	76	75	69	58	110	20
16	Rotary Kiln	95	92	88	83	81	80	72	68	63	120	21
17	Rubber Mill, Tire Rubber	102	99	97	90	89	84	78	77	74	210	36
18	Tread Tubers, Making Tire Casings	97	94	92	86	82	82	81	86	70	210	60
19	Curing Press, Rubber Tire Processing	96	89	87	86	85	87	85	88	88	240	72

†*See introductory paragraph at the beginning of appendix.*

TYPICAL SOUND PRESSURE LEVELS AND LOUDNESSES IN INDUSTRIAL PLANTS†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db. 37.5–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800	4800–9600	TOTAL LOUDNESS SONES	LOUDEST BAND SONES
	CHEMICALS—MACHINES (Cont'd)											
20	Heavy Service Curing, Rubber Tire Processing	93	90	85	86	83	78	75	75	66	130	22
	AREAS											
1	Ink Mill Room	86	76	80	79	79	79	75	72	70	97	19
2	Pigment Grinding	92	80	81	84	85	85	85	83	78	180	44
3	Pebble Mills	79	76	70	70	71	68	68	62	47	47	9.6
4	Enamel Mixing	76	71	68	66	65	70	59	50	43	31	10
5	Paint Drum Cleaning	85	74	77	80	76	74	75	74	65	93	22
6	Enamel Component Grinding	74	66	66	68	67	66	63	58	46	33	7.1
7	Rotary Kilns, Heavy Chemical	95	92	88	83	81	80	72	68	63	120	21
8	Vibrator, Heavy Chemicals Conveyor	94	91	89	83	78	81	78	81	78	160	37
9	Mixer, Heavy Chemicals	100	97	92	90	89	88	87	78	72	220	38
10	Gas Compressor Room	94	90	89	80	82	85	80	78	74	160	30
11	Catalytic Cracking Area, Petroleum	105	91	93	101	101	99	90	78	66	350	82
12	Pulverizing Room, Ball Mill, Compounders	99	85	85	85	85	92	94	93	92	330	120
13	Plastic Molding Area	101	100	92	89	86	87	77	78	78	210	39
14	Rubber Mill Department	97	95	92	86	84	77	74	72	66	150	26
15	Tread Tubers Area	97	94	92	86	82	82	81	86	70	210	60
16	Tire Making	105	100	101	98	92	85	85	83	76	300	51
17	Tire Making	98	92	88	91	92	85	83	83	84	230	44
18	Curing Area, Large Curing Presses	95	88	86	84	83	85	84	87	85	220	66
19	Curing Area, Curing Presses, Misc. Equip	93	90	85	86	83	78	75	75	66	130	22
20	Tire Making	94	92	85	87	77	74	70	67	60	110	20
21	Rubber Ply Building and Cutting	95	92	88	87	84	85	80	76	68	170	30
g	LEATHER											
	MACHINES											
1	Fleshing Machine, Clipping Hide Irregularities	95	82	85	90	87	86	85	77	62	180	35
2	Hair Dryer	98	97	88	81	90	75	68	64	59	130	35
3	Lime Mixing Tub, Hide Processing Tank	88	84	83	80	77	71	66	60	51	73	14
4	Setting Out Machine, Leather Processing	92	86	85	83	83	81	77	72	65	120	23
5	Splitting Machine	91	85	82	81	81	78	80	81	70	140	37
6	Coloring Drums	97	89	93	90	86	86	77	70	61	170	33
7	Setting Machine, Noise of Hair Cutting	108	90	90	91	105	103	98	90	82	500	130
8	Plating, Preparing Leather Surface	94	91	86	85	82	81	72	66	56	130	38
9	Plating, Preparing Leather Surface	88	87	77	74	72	69	67	64	59	65	12
10	Fine Hairing, Smoothing Irregularities	93	91	84	77	79	77	68	64	57	94	18
11	Seasoning Machine	92	90	85	81	80	72	67	64	59	94	18
12	Spraying Machine	93	88	88	87	76	72	68	68	65	100	23
13	Measuring Machine, Area of Leather Piece	77	74	72	63	60	60	52	50	50	24	4.6
	AREAS											
1	Hide Storage	79	75	75	71	64	59	54	41	33	28	6.2
2	Loading Area	79	77	73	69	66	61	58	50	38	31	6.1
3	Hide Trimming, Manual	82	81	72	70	72	63	58	53	49	39	9.9
4	Fleshing, Clipping Hide Irregularities	93	83	84	87	86	84	80	75	70	150	28
5	Unhairing Machine	91	88	81	83	80	76	71	64	58	95	18
6	Tanning Department	95	92	88	88	83	79	70	65	54	130	25
7	Wringing	93	86	87	87	83	83	78	76	74	150	26
8	Setting Out Dept., Hide Smoothing	92	84	85	83	83	79	77	72	65	120	22
9	Shaving, Splitting	89	86	83	81	79	76	74	74	68	110	20
10	Drum Coloring	95	89	89	87	85	84	79	70	62	150	28
11	Hide Processing, Drying	92	88	85	85	82	79	74	70	64	120	21
12	Setting, Cutting off Hairs	96	90	90	89	87	83	82	82	74	200	40

†*See introductory paragraph at the beginning of appendix.*

TYPICAL SOUND PRESSURE LEVELS AND LOUDNESSES IN INDUSTRIAL PLANTS†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db. 37.5 75	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600	TOTAL LOUDNESS SONES	LOUDEST BAND SONES
	LEATHER—AREAS (Cont'd)											
13	Drying Loft	96	92	93	85	76	79	71	72	52	130	28
14	Power House	116	109	115	91	79	73	68	68	64	270	120
15	Plating, Preparing Surface	94	91	86	85	82	81	72	66	56	120	23
16	Staking, Stretching, Smoothing Hides	90	88	84	80	74	68	67	59	52	75	14
17	Buffing and Brushing, Unrelated Mach. Noise	96	94	91	83	81	81	78	73	62	150	34
18	Seasoning, Hide Preparation	93	91	90	78	72	68	63	60	54	84	23
19	Trimming, Manual	84	83	73	69	64	61	57	50	44	34	7.4
20	Leather Sorting, Distant Noises	68	66	59	55	53	51	36	34	24	9	2.3
21	Bundling, Packaging	76	74	67	67	58	58	54	48	47	22	4.3
22	Shipping Department	78	77	67	61	58	58	47	43	34	19	4.0
23	Lime Processing	89	88	77	75	70	69	65	63	57	55	9.2
h	STONE, CLAY, GLASS MACHINES											
1	Clay Crusher	101	97	91	94	94	91	82	76	65	230	47
2	Clay Tile Extrusion Machine	93	89	86	85	83	81	72	68	56	120	23
3	Packing Machine, Glass Jars	95	90	87	87	84	83	83	83	83	200	44
4	Bottle Forming, Glass	100	95	96	90	92	92	89	92	93	380	110
5	Mixer, Glass Components	100	95	93	91	92	91	78	72	75	220	47
6	Bottle Forming, Glass	98	87	89	89	92	90	89	88	83	290	72
7	Carving Stone, Pneumatic Chipper	93	83	85	86	87	84	80	79	75	160	31
8	Cutting Stone, 14″ Cut Off Saw	90	80	78	81	83	83	84	85	81	180	55
9	Cutting Stone Blocks, 48″ Saw	92	82	81	85	83	85	84	83	81	180	44
10	Stone Planer, Flat	90	82	79	82	82	82	83	80	72	150	34
11	Stone Planer, Circle 12′, Concave Surface	101	85	93	89	94	95	94	89	76	350	90
12	Crane (Above 300 cps Area Levels) 7½ Ton	99	92	94	87	84	82	81	80	73	190	34
13	Crane (Above 300 cps Area Levels) 15 Ton	90	82	81	81	80	82	82	83	74	150	44
14	Cutting Large Stone, 72″ Saw	97	82	81	86	84	88	95	90	82	450	100
15	Light Weight Concrete Aggregate	101	94	97	96	90	88	82	76	71	240	44
16	Clay Tile Kiln (Unloading)	99	82	78	88	90	91	92	81	91	290	75
	AREAS											
1	Clay Crushing	101	97	91	94	94	91	82	76	65	230	47
2	Clay Tile Extrusion Department	80	76	71	70	71	70	63	66	54	50	10
3	Boiler Room, Clay Products Plant	86	80	79	79	73	75	76	69	60	84	18
4	Tile Molding, Noise is Distant Machinery	93	92	85	79	70	67	63	61	55	74	20
5	Drying Room, Clay Tile	80	79	73	68	68	63	57	50	36	32	6.6
6	Clay Tile Kiln, Unloading	69	58	56	63	64	65	58	53	46	25	7.1
7	Glass Jar Mold Shop, Machine Repairs	96	96	85	81	75	77	76	76	76	130	24
8	Glass Jar Mold Cleaning Shop	100	99	93	87	84	84	82	78	74	200	34
9	Glass Jar Packing Department	90	87	84	81	80	77	72	74	72	110	19
10	Bottle Forming	112	98	101	102	103	104	104	104	103	1100	420
11	Batch House, Glass Jar Plant	98	96	90	88	88	85	72	71	64	160	30
12	Mixing Area, Glass Jar Plant	100	95	93	91	92	91	78	72	75	220	47
13	Stone Carving Area (Many Machines Contributing)	89	83	83	81	81	79	77	76	73	120	24
14	Stone Planing Area (Many Machines Contributing)	87	82	78	78	77	79	79	78	72	110	28
15	Near Crane (Many Machines Contributing)	90	75	74	80	80	82	86	83	74	170	40
i	PRIMARY METALS MACHINES											
1	Pneu. Chip., 5′ x ½″ Steel Tank, Weld. Groove	122	109	112	108	114	117	113	112	113	2800	1000
2	Ped. Grinder, 14″, on ⅜″ x 12″ Angle Iron	92	75	74	78	77	82	83	85	88	160	49

†*See introductory paragraph at the beginning of appendix.*

TYPICAL SOUND PRESSURE LEVELS AND LOUDNESSES IN INDUSTRIAL PLANTS†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db. 37.5–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800	4800–9600	TOTAL LOUDNESS SONES	LOUDEST BAND SONES
	PRIMARY METALS—MACHINES—(Cont'd)											
3	Furnace, 30′ x 30′ x 8′, Oil, Ingot Heating	96	86	86	86	85	88	88	88	88	260	72
4	Furnace, 7′ x 4′ x 4′, Oil, Heating	103	98	98	94	92	92	85	77	74	280	48
5	Wood Planer, 30″ x 40″, 16″ x 12″ x ⅞″ Pine	108	80	77	102	94	100	105	98	73	720	250
6	Friction Saw, 46″, on 4″ x 4″ x ¼″ Steel Angleiron	107	88	91	89	95	100	101	101	100	760	300
7	Shakeout, 50 Sq. Ft., ½—1 Cu. Ft. Castings	114	110	109	102	105	106	99	97	90	790	160
8	Pneumatic Ram, 100 psi, Sand Mold Ramming	90	83	81	83	85	84	83	74	....	140	33
9	Shakeout, 40 Sq. Ft , ½—1 Cu. Ft. Castings	105	89	86	94	93	101	99	95	88	540	160
10	Tumbler, 36″ x 72″, Small Castings	100	78	78	86	91	95	95	92	92	390	105
11	Pneumatic Chipper, 100 psi., 1—3 Cu. Ft. Castings	110	88	90	95	96	97	106	104	106	1100	470
12	Push Up Machine, 14″ x 5″, Sand Molding	103	94	96	91	92	97	94	87	85	380	80
13	Core Blower, Making Sand Cores	116	86	84	86	87	108	101	110	114	1600	800
14	Core Draw Vibrator, Bench Cores	107	85	81	81	90	98	103	102	98	770	330
15	Shakeout, 10′ x 10′, 2—4 Cu. Ft. Castings	98	90	91	89	87	94	91	90	88	340	90
16	Pneu. Chipper, 100 psi, 1 Cu. Ft. Castings	102	90	90	90	89	94	95	93	92	410	140
17	Pneumatic Chipper, 100 psi, 4′—6′ Castings	112	82	84	83	90	109	109	100	96	840	340
18	Air Hoist, 2000 Lb., Pneumatic	112	92	84	88	87	93	93	96	110	620	230
19	Stand Grinder, 36″, Small Castings	96	88	87	88	86	92	83	81	81	180	50
20	Electric Furnace, 30 Ton, Early In Run	105	95	100	98	97	94	91	90	86	410	90
21	Sand Slinger, Air Rush and Sand Noise	102	90	96	94	94	94	91	87	88	350	69
22	Jolt Squeeze Machine, 13″, Sand Molding	100	87	90	87	91	96	91	92	84	350	110
23	Shakeout, 8′ x 5′ x 3′ Deep, 1 Cu. Ft. Castings	108	91	92	97	99	102	103	100	96	800	280
24	Pre-Mix Burner, 2″ Outlet, Gas, Crucible Heating	94	91	89	87	77	78	78	76	77	140	24
25	Roughing Mill, 30′ x 5′ Rolls, on 4′ x 2′ x ½″ Steel Plates	108	95	102	98	97	98	97	96	102	660	175
26	Leveler, 15′ x 8′ Area, for above Steel Plates	98	91	93	92	91	88	85	78	70	160	40
27	Decoiler, Uncoiling 2′ Wide Strip Steel Coils	116	95	94	93	97	108	107	110	112	1700	800
28	Anneal. Furn., 120′ x 60′ x 40′, Gas, Sheet Steel	101	98	84	91	95	84	77	71	70	190	48
29	Lectromelt Furnace, 60 Ton, Early In Run	103	94	98	97	93	93	81	76	70	270	54
30	Open Hearth, Five, Each 10′ Wide	90	88	84	78	77	76	71	69	68	96	16
31	Scarfing, Acetylene Weld. Equip.	91	78	74	67	73	84	83	84	86	140	45
32	Bloomer Mill, Strip Steel	95	85	90	88	87	88	81	81	74	190	36
33	Strip Mill, Steel	97	88	84	82	79	88	85	90	94	270	90
34	Conveyor, Strip Steel	102	82	82	89	96	97	92	86	81	320	77
35	Furnace, 12′ x 6′ x 6′, Heating Forgings	96	84	86	92	91	88	82	78	74	200	37
36	Forging Hammer, 3500 Lb., Steam Exh. Noise	109	86	88	93	91	92	95	102	107	750	330
37	Forging Manipulator, Air Exhaust Noise	101	85	86	90	92	95	92	90	95	370	90
	AREAS											
1	Chipping Area	102	84	85	86	89	91	96	97	101	510	190
2	Grinding Area, Noise Is From Chipping, etc.	92	75	74	80	79	87	87	79	84	170	47
3	Friction Saw Area, Noise Due To Distant Chipping	95	88	90	87	87	84	82	78	77	180	30
4	Shakeout Area, Noise Due To Shakeout	114	110	109	102	105	106	99	97	90	790	160
5	Pneumatic Ramming	91	80	81	83	85	84	83	74	72	140	33
6	Shakeout Area, Noise Due To Shakeout	99	85	86	91	93	95	93	90	86	370	90
7	Tumblers, Approx. 36″ x 72″, Small Castings	101	78	78	86	91	95	95	92	92	390	100
8	Shot Blast Room	98	82	82	85	87	91	91	91	92	320	100

†*See introductory paragraph at the beginning of appendix.*

TYPICAL SOUND PRESSURE LEVELS AND LOUDNESSES IN INDUSTRIAL PLANTS†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db. 37.5–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800	4800–9600	TOTAL LOUDNESS SONES	LOUDEST BAND SONES
	PRIMARY METALS—AREAS (Cont'd)											
9	Molding Area, Push-Up Machines, Shakeouts	103	94	96	91	92	97	94	87	85	380	80
10	Core Room, Core Molding By Machine	92	81	84	84	82	81	87	84	80	140	52
11	Core Room, Misc. Founding Equipment	90	85	82	81	81	81	78	77	74	130	26
12	Core Room, Core Draw Vibrators	90	82	81	81	84	83	76	75	71	130	28
13	Shakeout Area, Other Nearby Equip.	93	88	86	84	82	84	79	76	72	160	30
14	Casting Cleaning Area	97	88	88	88	88	91	85	88	82	250	66
15	Grinding Area, Noise of Handling Castings	93	86	86	84	82	88	77	80	81	160	38
16	Electric Furnace Area	105	95	100	98	97	94	91	90	86	410	90
17	Sand Slinger Area, Other Foundry Operations	93	85	86	87	85	82	74	70	68	130	26
18	Steel Pouring Area, Tumbling. Shakeout Noises	91	86	85	84	75	79	74	73	72	110	24
19	Roughing Mill Area, Handling ½" Steel Plate	97	92	90	83	87	93	79	72	77	190	53
20	Steel Handling Area, Strip Coiling	87	78	78	79	78	85	74	65	62	68	30
21	Annealing Furnace Area	84	76	78	73	80	76	65	63	60	62	18
22	Lectromelt Furnace Area, Start of Melt	97	88	94	90	88	85	78	74	70	180	31
23	Lectromelt Furnace Area	92	80	90	84	81	78	75	72	70	120	23
24	Open Hearth Area	90	88	84	78	77	76	71	69	68	96	16
25	Scarfing Area, Misc. Distant Billet Handling	78	72	65	67	70	73	69	60	60	47	13
26	Bloomer Mill Area	95	85	90	88	87	88	81	81	74	190	36
27	Strip Mill Area	98	88	84	82	79	88	85	90	94	270	90
28	Conveyor	101	82	82	89	96	97	92	86	81	320	77
29	Drop Forge Area, Distant Operations	91	84	86	85	80	78	74	68	70	110	20
30	Blast Furnace Area	74	69	62	60	56	53	50	51	46	16	3.2
j	FABRICATED METAL PRODUCTS MACHINES											
1	Friction Saw. 46", on 4" x 4" x ¼" Steel	107	88	91	89	95	100	101	101	100	760	300
2	Milling Machine, Working Engine Block	93	76	77	87	88	87	82	78	74	160	33
3	Boring Machine	97	76	80	80	85	93	92	87	82	250	77
4	Pneumatic Press, Assembling Bearing on Shaft	100	74	76	88	85	94	91	94	96	370	140
5	Hob-grinder	91	78	78	78	75	74	79	84	88	150	48
6	Multiple Drill, On Piston Parts	98	78	81	91	93	95	85	77	75	220	64
7	Turret Lathe, Ram Type, On Piston Parts	104	84	84	83	79	87	102	101	93	620	300
8	Sprocket Grinder, Pneu., 1' Dia., 36" Castings	96	92	88	88	85	84	83	83	82	210	48
9	Hand Grinder, Pneu., 5" Dia., 24" Castings	98	86	85	94	91	88	89	84	82	260	55
10	Stand Grinder, 36", Small Castings	96	88	87	88	86	92	83	81	81	180	50
11	Nail Machine, Roofing Nails	110	96	96	94	97	106	102	101	98	850	300
12	Hoop Machine, No. 11 Ga. Steel Wire	101	97	90	87	85	98	87	84	81	270	66
13	Fence Wire Machine, Forming Steel Wire Parts	100	84	82	81	81	96	94	96	95	410	170
14	Wire Drawing Machine	95	84	88	88	85	90	81	76	80	180	44
15	Fence Machine, Forming Steel Wire Into Fence	92	79	81	81	81	91	83	81	82	170	46
16	Wire Drawing Machine	90	78	84	85	83	84	73	68	67	120	28
17	Turret Lathe, 3" Hole In C. R. S., Noise of Worn Parts	91	81	85	78	80	84	84	82	81	160	37
18	Tracer Lathe, 4' x 4", Gear Noise, Cutting Squeal	95	92	85	83	87	86	81	79	74	170	32
19	Turret Lathe, On 3" C. R. S.	92	82	74	79	82	83	79	87	84	170	65
20	Gear Shaper	88	72	75	78	81	83	81	79	76	130	30

†*See introductory paragraph at the beginning of appendix.*

TYPICAL SOUND PRESSURE LEVELS AND LOUDNESSES IN INDUSTRIAL PLANTS†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db. 37.5 75	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600	TOTAL LOUDNESS SONES	LOUDEST BAND SONES
	FABRICATED METAL PRODUCTS—MACHINES (Cont'd)											
21	Vertical Radial Drill, 2″ Dia. on Light Casting	93	77	79	78	79	89	85	85	82	180	55
22	Turret Lathe, Sprocket Cut	97	87	79	79	77	86	95	89	83	240	100
23	Arc Welder, on ½″ Steel Plate	86	84	76	80	76	81	78	76	78	120	24
24	Automatic Drop Hammer, Small Hardened Tools	111	97	94	95	100	106	103	105	104	1100	450
25	Automatic Punch Press, Air Blast Only, Small Tools	107	98	96	96	91	100	97	100	104	670	270
26	Pedestal Grinder, 36″, on Small Tools	106	76	78	76	81	97	90	98	105	530	220
27	Cutting Machine, on Hardened Tools	113	106	108	106	101	104	97	95	98	760	150
28	Sand Blast Machine, Four Position, on Hand Tools	118	87	86	88	94	100	108	113	115	2100	1200
29	Lead Pot Furnace, on Hand Tools	84	77	78	75	75	76	70	74	68	81	18
30	Lead Stirring Motor, Air Exhaust	110	82	81	80	81	87	103	107	103	1000	630
31	Pneumatic Vibrator, Removing Sand Mold Pattern	100	76	74	76	89	84	93	97	94	400	210
32	Core Blower, Sand Cores	102	82	80	78	88	98	89	93	99	370	120
33	Sand Muller, 1500 Lbs., For Mixing Sand	96	78	88	94	84	86	82	78	72	180	38
34	Tumbler, 6′ x 3′, Small Castings	97	85	83	82	82	91	91	90	90	280	90
35	Shot Blast, With Conveyor, Small Castings	100	86	88	87	87	98	88	84	83	270	76
36	Pre-Mix Burner, 2″ Outlet, Gas, Crucible Heating	94	91	89	87	77	78	78	76	77	150	24
37	Blower, For Cupola, 15″, Ducted Air	97	92	91	92	87	79	77	74	74	170	33
38	Milling Machine, Channel Cut, 10″ x 2″ x 2″ Steel	90	86	83	78	79	84	85	82	83	170	40
39	Pneumatic Hammer, 100 psi, Peening Operation	104	85	84	84	85	94	93	96	102	500	190
40	Butt Welder, Electric, on Tool Parts	91	88	76	70	79	88	84	83	83	160	40
41	Back Shear, Four-Cutter, for ⅛″ Steel, Operating	95	80	86	88	87	90	88	80	77	210	57
42	Roll Grinder, Truing 4′ x 30″ Roughing Mill Rolls	85	80	79	78	79	83	75	76	78	80	27
43	Shaper, Small Steel Parts	95	88	86	88	88	92	86	84	75	230	50
44	Corrugating Machine, on Sheet Steel	111	95	92	92	95	108	99	106	101	1000	500
45	Downspout Roll, on Sheet Steel	94	88	88	89	89	90	80	80	75	200	43
46	Corrugating Machine, Sheet Steel Riveting	114	102	98	98	95	112	107	104	101	1200	410
47	Liming Machine, Sheet Steel Processing	87	61	64	69	78	86	70	65	62	78	32
48	Automatic Screw Machine, Nut Blanking, 1¼″ Stock	97	88	89	87	91	88	82	82	88	220	40
49	Chip Separator, Shake Table Type, Nuts and Bolts	95	87	88	87	88	89	82	80	87	200	37
50	Automatic Screw Machine, Blanking ½″ Brass Nuts	91	80	85	83	82	81	80	78	82	140	26
51	Hot Bolt Head Upsetter, on ½″ Bronze Bolts	111	90	90	88	90	107	107	96	102	840	310
52	Toggle Machine, Cold Header, No. 2—10 Screw Heads	101	89	88	96	93	94	90	86	87	240	63
53	Punch Press, 25 Ton, ⅜″ Brass Washers	101	90	90	90	92	98	90	87	93	350	72
54	Nut Former, ½″ Stock	97	91	89	91	85	87	81	80	85	210	35
55	Tumbler, Nuts, Bolts	95	82	84	84	83	86	86	86	91	220	60
56	Nut Tapper, ½″ Stock	94	78	80	83	83	86	86	88	87	220	73
57	Automatic Screw Slotter, ¼″ Bolts	96	78	82	84	87	92	88	87	88	250	67
58	Roll Threader, ¼″ Bolts	92	80	83	83	84	86	85	84	83	190	49
59	Spin Riveter, ¼ Hp, Electric, on Thin Steel Chassis	103	77	73	77	86	88	96	97	100	440	170

†*See introductory paragraph at the beginning of appendix.*

TYPICAL SOUND PRESSURE LEVELS AND LOUDNESSES IN INDUSTRIAL PLANTS†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db. 37.5–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800	4800–9600	TOTAL LOUDNESS SONES	LOUDEST BAND SONES
	FABRICATED METAL PRODUCTS—MACHINES (Cont'd)											
60	Radial Drill Press. 4′ Arm, on Engine Block	90	84	81	81	81	86	79	77	74	140	33
61	Autom. Lathe. on 8″ Dia. Gray Iron Flange	88	76	75	74	76	78	86	76	76	120	44
62	Multiple Drill Press, 42 Spindle, on Engine Block	91	82	80	82	85	84	81	76	78	140	28
63	Vert. Tur. Lathe, 42″, on 5″ Thick Casting	88	76	75	76	81	82	82	76	71	120	30
64	Tumbler. 9 Cu. Ft., 3″ Steel Discs	87	76	77	75	76	79	82	79	72	110	30
65	Autom. Radiator Washers, Gas Fired Conveyor	97	84	84	89	94	89	80	74	66	180	45
66	Furnaces, Non-ferrous	105	85	95	104	92	90	75	69	64	230	74
67	Router, on Aluminum Stock	95	89	89	89	87	81	77	75	75	170	27
68	Hand Operated Pneu. Drill, on Aluminum Stock	92	86	85	80	75	76	86	84	77	170	49
69	Autom. Screw Machine, Cutting ½″ Bronze Bushings	94	77	77	76	81	84	87	89	90	210	73
70	Welded Tube Mach., Making Tube From Strip	91	84	87	82	75	77	72	72	58	100	18
71	Grinding Machine, on 2″ Metal Tubing	94	82	84	81	80	85	87	88	84	210	72
72	Electric Hand Grinder, 8″, on Steel Pipe	91	84	81	81	81	83	84	82	72	160	40
73	Grinding Machine, on 20′ x 4″ Pipe	99	86	85	82	94	95	89	86	82	280	62
74	Grinding Machine, on Steel Pipe	98	89	87	87	92	91	90	86	80	270	62
75	Grinding Machine, Metal Parts	91	82	82	81	83	83	81	84	78	160	49
76	Polisher, on 20′ Metal Tubes	95	84	85	88	87	85	84	89	88	240	80
77	Hand Grind, 4″ Electric, 1′ Steel Pieces	92	85	87	87	84	79	76	76	72	140	24
78	Pointing Machine, Steel Parts	103	98	99	96	90	88	78	74	64	240	45
79	Steel Conveyor, 30′ Steel Rods	107	98	93	93	96	102	104	100	93	790	270
80	Rotary Hammering Machine, 20′ x 2″ Steel Tubes	100	93	93	95	94	91	88	86	77	300	60
81	Pipe Mill, Processing Platform	95	89	87	87	86	89	88	86	78	240	60
	AREAS											
1	Machine Shop, Lathes, Presses, etc. (Steel)	85	71	75	76	77	80	77	75	72	97	22
2	Machine Shop, Lathes, Hob-Grinders	85	....	77	78	74	73	76	78	78	100	28
3	Metal Working, Grinding, Handling Castings	89	86	81	78	77	78	78	75	70	110	22
4	Grinding Area, Noise of Handling Castings	93	86	86	84	82	88	77	80	81	160	38
5	Nail Manufacturing Area, Nail Mach's.	103	86	88	88	91	98	96	95	92	460	300
6	Steel Wire Fence Manufacturing	102	84	82	81	81	96	94	96	95	410	170
7	Wire Drawing Area, Drawing Machines	95	84	88	88	85	90	81	76	80	180	44
8	Steel Wire Fence Manufacturing	94	79	81	81	81	91	83	81	82	170	46
9	Machine Shop, Lathes, Borers	83	78	71	75	74	77	71	70	67	74	17
10	Arc Welding Area, Steel Parts	84	78	76	76	73	76	76	75	63	88	22
11	Automatic Drop Hammer Area, 30 Mach's.	108	90	89	93	95	104	97	97	94	590	190
12	Automatic Punch Press Area, 12 Mach's.	105	98	96	96	91	98	95	94	98	520	130
13	Grinding Area, 36″ Machines, Small Tools	89	76	76	75	75	83	78	81	85	130	37
14	Grinding Area, 12 Machines, Var. Sizes, Steel	86	76	75	73	77	78	77	77	78	100	26
15	Milling Mach. Area, 20 Mach., Steel Pts.	86	76	75	75	75	82	76	73	68	94	24
16	Heat Treating Area, Lead Pots, Furnaces	83	76	75	74	75	76	69	65	66	67	16
17	Sand Molding Area, Small Tool Castings	83	79	75	76	69	71	69	67	62	61	11
18	Core Area, Noise Due to Air Blast	79	72	76	69	67	68	67	64	62	47	8.8
19	Shot Blast Area, Noise Due to Shot Machinery	88	82	80	82	79	78	72	70	70	97	18
20	Steel Pour Area, Tumbling, Shakeout Noises	91	86	85	84	75	79	74	73	72	110	19
21	Cupola Area, Cupola Down, Blower Noise	97	92	91	92	87	79	77	74	74	170	33
22	Tool Mfr. Area, Hum of Electric Butt Welder	86	83	77	73	71	76	76	70	65	81	18

†*See introductory paragraph at the beginning of appendix.*

TYPICAL SOUND PRESSURE LEVELS AND LOUDNESSES IN INDUSTRIAL PLANTS†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db. 37.5–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800	4800–9600	TOTAL LOUDNESS SONES	LOUDEST BAND SONES
	FABRICATED METAL PRODUCTS—AREAS (Cont'd)											
23	Rolling Mill Mach. Shop, Loc. and Dist. Noise	88	76	79	78	82	84	75	74	72	110	27
24	Rolling Mill Mach. Shop, Lathes, Drills	89	88	82	68	67	71	65	61	62	61	12
25	Corrugating Area, Sheet Steel, Sev. Mach.	100	96	90	85	86	97	87	76	77	200	72
26	Strip Steel Processing, Lining Area	82	62	63	60	60	82	70	58	60	50	24
27	Screw Machine Area, Bolts	93	76	74	84	84	85	82	82	88	160	40
28	Automatic Screw Machine Area, Nuts	87	78	79	79	79	79	75	75	76	100	22
29	Automatic Screw Machine Area, Small Parts	91	75	75	81	81	84	84	82	84	160	40
30	Automatic Screw Machine Area, Slotted Components	78	74	70	68	67	70	75	59	60	51	17
31	Light Riveting Area, Small Steel Chassis	80	76	70	70	69	66	68	66	69	51	10
32	Machine Shop, Drill Presses, Borers, etc.	88	83	78	77	79	80	75	74	74	100	21
33	Machine Shop, Drill Presses, Borers, etc.	84	77	75	72	74	75	76	72	73	82	18
34	Machine Shop, Drill Presses, Borers, etc.	87	80	78	79	81	82	79	75	71	120	24
35	Machine Shop, Drill Presses, Borers, etc.	85	75	74	74	76	80	76	74	71	92	21
36	Machine Shop, Drill Presses, Borers, etc.	83	76	75	74	75	75	74	72	68	77	18
37	Machine Shop, Drill Presses, Borers, etc.	85	80	78	75	75	75	75	75	70	92	22
38	Machine Shop, Drill Presses, Borers, etc.	85	74	77	75	77	77	75	75	74	91	22
39	Punch Press Department, Approx. 20 Mach.	93	80	83	83	83	88	85	83	80	190	44
40	Non-ferrous Foundry Furnace Area, 6—10 Furn.	105	85	95	104	92	90	75	69	64	230	74
41	Radiator Processing Area	97	84	84	89	94	89	80	74	66	180	45
42	Machine Shop, Screw Machines, Metal Working	87	75	75	76	81	80	79	80	76	120	34
43	Machine Shop, Lathes, Grinder, Saws	79	77	73	73	72	73	66	58	48	51	13
44	Storeroom, Tools, Materials	66	64	55	54	49	49	43	38	32	9	2.0
45	Pickling Area, Dist. Steel Handling Noise	88	84	82	80	79	76	68	62	62	82	17
46	Steel Fabrication Area, Handling, Cutting	91	88	85	84	80	81	71	68	63	110	23
47	Steel Fabrication Area, Handling, Cutting	93	86	87	87	86	81	78	73	68	140	27
48	Steel Fabrication Area, Handling, Cutting, Processing	101	92	95	94	96	87	78	72	62	220	38
49	Shipping Dept. (Steel Plant) Dist. Noise	76	70	71	70	67	62	54	52	58	29	6.6
50	Steel Finishing Dept., Lathes, Saws	84	80	78	77	74	71	63	59	52	58	12
51	Steel Polish and Grind Area	91	84	81	81	78	79	84	83	78	150	44
52	Steel Handling Area	94	88	89	87	84	83	82	78	70	170	30
53	Steel Parts Sawing Area, Handling Noise	92	88	85	83	82	79	73	68	68	110	21
54	Steel Processing Area, Handling Noise	96	89	89	88	87	88	82	79	72	190	38
55	Steel Working Area, Handling Noise	93	88	86	85	84	79	78	72	64	130	24
56	Power Plant Area, Alternators, Reciproc. Machy.	98	95	87	89	86	83	77	74	64	170	27
57	Shipping Department, Distant Steel Handling	85	80	80	77	70	67	64	63	52	56	11
k	MACHINERY MACHINES											
1	Engine Dynamometer Stand	99	96	88	88	84	82	90	89	90	290	79
2	Pneumatic Wrench, Engine Head Nuts	103	83	85	94	94	95	95	95	95	450	160
3	Milling Machine, Working Engine Block	93	76	77	87	88	87	82	78	74	160	33
4	Boring Machine, Working Engine Block	97	76	80	80	85	93	92	87	82	250	77
5	Pneumatic Press, Assembling Bearing on Shaft	101	74	76	88	85	94	91	94	96	370	140
6	Hob-Grinder	91	78	78	79	75	74	79	84	88	150	48

†*See introductory paragraph at the beginning of appendix.*

Typical Sound Pressure Levels and Loudnesses in Industrial Plants†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db.								TOTAL LOUD-NESS SONES	LOUD-EST BAND SONES
			37.5 75	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600		
	MACHINERY—MACHINES (Cont'd)											
7	Multiple Drill, on Piston Parts	99	78	81	91	93	95	85	77	75	220	64
8	Turret Lathe, Ram Type, on Piston Parts	105	84	84	83	79	87	102	101	93	620	300
9	Welder, 600 amp., on Steel Castings	110	86	86	82	89	98	105	106	102	1000	470
10	Pneu. Riveting Hammer, 20′ x 8′ Dia., x ¾″ Steel Tank	131	121	124	123	122	121	121	118	122	5400	2000
11	Pneu. Chipper, 24′ x 4′ Dia., x ½″ Tank	127	96	92	116	107	118	121	122	122	5900	3000
12	Pneu. Chipper, 10′ x 8′ Dia., x ½″ Tank	126	106	107	108	113	118	117	116	124	4100	1500
13	Pneu. Chipper, 12′ x 8′ Dia., x ½″ Tank	129	122	120	119	118	120	119	120	122	5400	2400
14	Hand Grinder, Electric, 12″, 8″ Thick Steel Plate	97	69	72	75	93	90	87	88	88	240	73
15	Arc Welder, on ½″ Steel Plate	86	84	77	80	76	81	78	76	78	120	24
16	Pneu. Air Hoist, 4000 Lb.	102	82	88	84	77	88	85	90	101	320	90
17	Pneu. Wrench, on Engine Nuts	105	78	78	78	85	96	100	97	100	550	200
18	Int. Comb. Engine Test, 150 Hp. Each	102	86	90	98	91	94	92	90	90	370	90
19	Steel Plate Shear, for 6′ x ¼″ Steel, Idling	98	92	88	87	90	93	87	78	76	230	53
20	Back Shear, Four-Cutter, For ⅛″ Steel, Operating	95	80	86	88	87	90	88	80	77	210	57
21	Engine Lathe, 60″, on 40′ x 1′ Steel Shaft	94	79	82	86	90	87	81	71	69	160	35
22	Engine Lathe, 60″, on 30′ x 1′ Steel Shaft	92	86	85	86	77	87	79	65	66	140	37
23	Gas Welder, No. 6 Tip, Cutting 15″ Steel	95	83	84	83	84	86	87	86	91	240	66
24	Gas Engine Test, 600 Hp.	99	94	95	90	86	87	86	86	84	270	60
25	Gas Engine Test, 200 Hp.	116	104	107	100	99	100	103	107	113	1440	570
26	Stud Driver, Pneu. ⅜″ Engine Studs	95	82	81	80	89	88	85	87	87	230	66
27	Automatic Radiator Washer, Gas-Fired, Conveyor	97	84	84	89	94	89	80	74	66	180	45
28	Riveting Jig, Airplane Wing Assembly	116	88	94	96	97	104	108	111	113	1800	900
29	Internal Combustion Engine Test, 1500 Hp.	116	101	103	107	111	110	107	106	104	1400	500
	AREAS											
1	Shot Blast Room, Small Castings	98	82	82	85	87	91	91	91	92	320	100
2	Engine Dynamometers	97	94	87	85	84	82	85	84	85	210	49
3	Machine Shop, Lathes, Presses, etc.	85	71	75	76	77	80	77	75	72	97	22
4	Machine Shop, Hob Grinding Area	85	77	77	78	74	73	76	78	78	100	28
5	Assembly Shop, Grinding, Pneu. Chipping	91	86	84	83	79	80	81	79	74	150	31
6	Pneu. Rivet. Area, Large Steel Plate Tanks	105	85	81	90	91	99	99	96	98	550	170
7	Pneu. Chip. Area, Cleaning Steel Tank Welds	113	92	95	94	103	102	107	108	108	1400	630
8	Hand Grinding Area, Steel Plate	85	80	78	79	77	76	69	66	61	77	16
9	Arc Welding Area, Steel Parts	84	78	76	76	73	76	76	75	63	88	22
10	Pneu. Air Hoist, 4000 Lb.	84	76	76	77	75	76	74	75	72	89	22
11	Int. Comb. Eng. Testing, 150 Hp. Each	88	85	85	74	72	76	73	68	67	88	16
12	Earth Moving Equipment Assembly	91	85	86	81	82	84	75	71	71	120	28
13	Steel Plate Shear, for ¼″ Steel, Idling	98	92	88	87	90	93	87	78	76	230	53
14	Engine Lathe, 60″, on 1′ x 40′ Steel Shaft	90	77	80	85	85	84	78	70	67	120	28
15	Engine Lathe, 60″, on 1′ x 30′ Steel Shaft	88	81	84	81	76	77	72	64	62	87	17
16	Compressor Test, 100—300 Hp. Int. Comb. Eng.	105	100	99	95	92	95	92	93	91	450	120
17	Engine Test, 50 Hp. Int. Comb.	109	98	107	100	92	95	88	87	82	400	74
18	Machine Shop, Lathes, Drills, Borers	87	83	82	72	74	77	75	73	67	91	19
19	Machine Shop Area, Lathes, Drills, etc.	85	81	80	70	70	72	70	66	66	65	12
20	Punch Press Room, Electrical Parts, Steel	86	78	76	77	79	80	79	79	78	120	31
21	Punch Press Room, Electrical Parts, Steel	90	81	81	80	81	82	84	83	83	170	44

†*See introductory paragraph at the beginning of appendix.*

TYPICAL SOUND PRESSURE LEVELS AND LOUDNESSES IN INDUSTRIAL PLANTS†

NO.	INDUSTRY	OVER-ALL LEVEL db.	OCTAVE BAND LEVELS, db. 37.5–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800	4800–9600	TOTAL LOUDNESS SONES	LOUDEST BAND SONES
	MACHINERY AREAS (cont'd)											
22	Punch Press Room, Electrical Parts, Steel	97	83	85	84	89	89	90	90	89	290	89
23	Punch Press Room, Electrical Parts, Steel	100	86	86	86	92	91	93	93	91	360	120
24	Int. Comb. Eng. Test Area, 1500 Hp.	104	86	92	97	100	96	96	91	85	440	110
25	Radiator Processing Area	95	84	84	89	94	89	80	74	66	180	45
1	**AIRCRAFT MANUFACTURE MACHINES**											
1	Pneu. Riveting Gun, Sub-assembly	133	118	123	122	120	129	123	125	127	5800	1700
2	Pneu. Riveting Gun, Sub-assembly	125	118	115	116	112	113	114	115	120	3400	1400
3	Pneu. Riveting Gun, Wing Assembly	106	84	81	85	93	90	101	103	104	750	380
4	Riveting Hammer, Fuselage Assembly	108	102	101	101	98	99	98	94	103	690	150
5	Pneumatic Drill, 1/8" Holes in Aluminum	91	86	76	76	75	85	82	84	85	170	49
6	Bumping Hammer, on Thin Metal	112	86	94	103	108	109	107	104	101	1200	420
7	Circular Saws, Cutting Metal	105	69	70	82	86	88	86	98	103	460	220
8	Rivet Bucking, Wings	105	82	86	88	96	94	100	101	96	670	300
9	Rivet Bucking, Fuselage	90	75	78	80	93	85	82	80	88	180	42
10	Router, on Aluminum Stock	95	89	89	89	87	81	77	75	75	170	27
11	Hand Operated Pneu. Drill, Aluminum Stock	92	86	85	80	75	76	86	84	77	170	49
12	Riveting Jig, Wing Assembly	116	88	94	96	97	104	108	111	113	1800	900
	AREAS											
1	Routers, Riveting	92	88	86	83	80	81	76	76	70	130	24
2	Aluminum Machining	88	86	79	77	74	73	69	68	54	73	12
3	Sub Assembly, Light Riveting	88	86	78	77	76	74	71	70	62	81	14
4	Sub Assembly, Distant Riveting	91	89	83	79	78	73	70	64	60	89	15
5	Sub Assembly, Distant Riveting	93	89	86	82	80	81	84	74	67	140	30
6	Wing Assembly, Distant Riveting	91	83	79	82	79	80	80	85	82	160	55
7	Fus. Assem., Dist. Riveting	88	86	77	76	76	76	73	74	65	90	20
8	Fus. Assem., Dist. Riveting	86	84	77	74	73	72	67	61	54	64	11
9	Sub Assembly, Dist. Riveting	86	85	77	74	72	71	66	62	53	60	10
10	Assembly, Distant Riveting	86	84	77	77	74	73	70	67	56	75	14
11	Assembly, Distant Noises	89	87	79	80	76	76	73	69	57	90	16
12	Assembly, Distant Noises	89	86	78	81	82	78	74	70	60	98	19
13	Assembly, Distant Noises	88	84	83	80	78	71	68	60	52	77	15
14	Assembly, Distant Noises	85	84	75	75	71	67	62	58	45	50	9
15	Small Parts Assembly	88	84	82	79	78	72	70	68	62	83	15.9
16	Wing Rivet. Bucking Area	83	69	73	73	74	74	69	72	70	70	18
17	Stamping, Shears, Grinding	83	73	75	75	75	74	73	72	70	77	18
18	Riveters, Routers, Grinders	89	74	81	82	83	74	78	77	76	123	26
19	Wing Assembly, Distant Riveting	84	62	68	72	76	73	78	79	77	95	31
20	Wing Assembly, Distant Riveting	83	67	72	74	73	77	78	76	65	88	24
21	Main Assembly, Distant Riveting	81	68	72	71	71	74	75	75	65	75	22
22	Fuselage Assembly, Distant Riveting	84	68	71	72	78	77	77	76	70	91	24
23	Router Area, Distant Riveting	92	78	78	81	85	84	84	83	82	170	44
24	Small Parts Assembly, Distant Riveting	86	73	75	76	76	78	79	79	78	110	31
25	Small Parts Assembly, Distant Riveting	82	64	72	71	72	74	75	74	71	75	20
26	Wing Dept., Sm. Saws, Aluminum	80	67	68	67	67	68	70	76	75	64	24

†*See introductory paragraph at the beginning of appendix.*

Reducing Industrial Noise

GENERAL PRINCIPLES

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I. Introduction

THE PROBLEM of noise in industry is currently receiving much attention because, in recent years, noise has become generally more intense and widespread due to the speeding up of machines and the increase in mechanization of industry, and because there is increasing concern for the safety, efficiency, and morale of personnel. Several symposia[1,2] on noise have emphasized the problem and discussed methods of controlling noise in industry. Useful material is also contained in a German book on noise control engineering.[3] Noise control has also been the subject of numerous articles in various publications, including the *Journal of the Acoustical Society of America*. Since the cost of noise reduction must be balanced against benefits which may not show directly in the balance sheet, efforts are usually concentrated in areas where noise conditions are definitely bad. Incentives for noise reduction, therefore, vary roughly with intensity or loudness. The major efforts will and should be concentrated on high intensity noise which is more likely to be harmful to hearing, prevents warning signals from being heard, and interferes with speech communication. The control of less intense noise which affects efficiency through decreased comfort and morale is less urgent. Furthermore, it is very difficult to estimate the effect of moderate noise on people because of the many conflicting psychological factors involved.

The purpose of this paper is to discuss practical methods of noise reduction which can be used by the plant engineer, machine designer, safety engineer and industrial hygienist. It should be remembered, however, that noise reduction is a complex subject in many cases and consultation with trained acoustical engineers is advisable in order to avoid unnecessary expense. The engineer in charge of noise reduction should establish design goals for safe or desirable noise levels and should be familiar enough with the principles of sound to be able to estimate the amount of sound reduction which is possible by various methods. The costs of quieting can then be weighed to obtain a satisfactory solution without expensive overdesign. Although the general principles of noise control to be discussed have wide application, the scope of most of the discussion is limited to loud industrial noise inside buildings. The emphasis is on intense noise with little attention to noise of lower level which may be transmitted to non-noisy areas such as offices. Also excluded from the scope are such unusual cases as jet engine test cells and special problems such as ventilation ducts which should be handled by specialized installers.

II. Noise Level Goals

LIMITS which industrial noise should not exceed are poorly defined for several reasons: (1) Masking of warning signals and speech in steady noise is fairly well defined, but information is not available for setting exact limits for hearing damage. (2) Practical limits on noise will vary with the type of operation (some industrial processes are inherently noisy), and with the number of workers and the time of exposure to the noise. (3) For many intermittent noises, it is not possible to make accurate measurements of noise by any accepted methods. Such noises may be objectionable, however.

In spite of these factors, broad design goals can be set up for loud, fairly steady noises which affect safety and speech in-

terference. Intermittent noise can be treated by estimating how loud or uncomfortable it is when compared with measurable steady noise.

A. MEASUREMENT OF NOISE:

It is well established that noise measurement must include some sort of weighting for the distribution of energy with frequency. For instance, the rumble of a truck on an uneven floor may have the same sound pressure as the high pitched squeal of a circular saw, but the hearing mechanism is affected more by the high pitched noise in nearly every way.

At present there is no equipment which directly obtains a meaningful noise rating on a meter. Equipment is available, however, for analyzing or measuring noise in bands of frequency and these results can be used to determine loudness, speech interference, etc. Octave band filters are used in combination with sound level meters and the results adequately describe most steady state noise with regard to its major effects on humans. "The Measurement of Industrial Noise"[4] by G. L. BONVALLET gives practical details of noise measurements and a useful bibliography. For more technical information reference can be made to texts such as "Acoustic Measurements"[5] by L. L. BERANEK.

Most of the illustrations of noise given later will be plotted either as sound pressure levels in octave bands or in loudness charts[6] so that comparisons of loudness of different noises can be made. Fig. 1 is an example of graphs of noise measured in octave bands. It is emphasized that the overall levels of 94 and 103 db. in the upper section of Fig. 1 have little meaning in regard to the effect on the listener. Total loudnesses of 500 and 170 sones, which are the sums of the loudnesses in each band of the lower part of the figure, agree well with noise evaluation by listening.

In addition to using noise measuring instruments, it is advocated that noise engineers learn to listen objectively. Although ears are not as good as instruments in accurately comparing noises before and after a lapse of time, they certainly excel in portability, availability, and freedom from maintenance, and surprisingly good judgments can be made with a little training. For loud noises, the sound level in the speech frequency bands can be estimated

Practical methods of noise reduction are discussed for use of people in industry. By way of introduction, noise level design goals are discussed and the causes of noise generation are presented. The part on design goals briefly describes (a) criteria for hearing damage which are unfortunately rather uncertain and require much more work before acceptance, and (b) speech interference levels which are important for safety and communication. The next section on the generation of noise describes sources, noise flow diagrams, transmission, radiation, reflection and absorption, all of which are important when noise reduction is concerned.

The material on noise reduction starts with some brief but important information on operational planning including selection of work processes and plant layout, and on use of protective devices. A description is given of reduction techniques at noise sources, along flow paths, at radiating areas, and in working areas. Reduction of radiation, solid-borne and airborne transmission, resonances, and other phenomena by the use of suitable materials, devices, and constructions is described. A detailed discussion is given on the absorption of noise and the effect of ceiling and wall absorption materials.

Examples of simple and practical methods of noise reduction are given for some common industrial noise problems. The conclusion calls attention to the need for cooperation between the several parties concerned to arrive at necessary compromises in providing noise reduction. As a long term program in the quest of better noise information and reduction techniques a number of unsolved problems are mentioned. These involve hearing impairment criteria, effect of transient (rather than steady) noises upon hearing, engineering specifications of ear defenders, and substitution of less noisy operations.

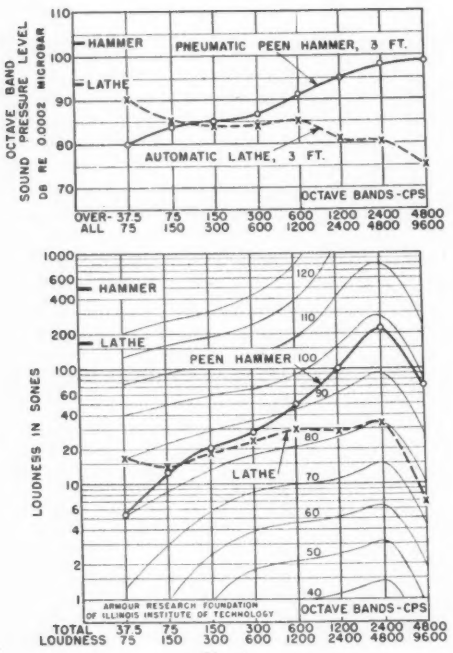
OCTAVE BAND SOUND PRESSURE LEVEL DB RE 0.0002 MICROBAR
HAMMER
LATHE
PNEUMATIC PEEN HAMMER, 3 FT.
AUTOMATIC LATHE, 3 FT.
OCTAVE BANDS-CPS
OVER-ALL
37.5 75 150 300 600 1200 2400 4800
75 150 300 600 1200 2400 4800 9600
LOUDNESS IN SONES
HAMMER
LATHE
PEEN HAMMER
ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY
OCTAVE BANDS-CPS
TOTAL LOUDNESS
37.5 75 150 300 600 1200 2400 4800
75 150 300 600 1200 2400 4800 9600

Fig. 1.

Octave band levels and loudnesses for two industrial noises. The graph at the top of the figure indicates roughly the distribution of the noise energy over the audible frequency range for two industrial noises. The same data plotted according to loudness contours on the lower chart indicate according to the scale at the left the relative loudness contributions by the various frequency bands and yield valuable information for noise reduction design.

from the distance at which shouted speech can be understood. Listening is particularly useful in quickly separating areas of intense noise from those which have a lower or acceptable level.

B. NOISE LEVEL CRITERIA:

There is much uncertainty concerning allowable noise limits with respect to hearing damage. KRYTER[7] has made an exhaustive survey of the literature up to 1950. Damage criteria which have been published have necessarily been tentative and are qualified as approximate levels of steady noise where damage is likely for some individuals who are exposed every working day for long periods of time. A damage criteria curve was given by PARRACK[8] based on KRYTER'S report[7] and modified at the low frequencies following BERANEK.[9] HARDY[10] published octave band curves giving limits which bracket the zones of possible and probable damage. A subcommittee of the American Standards Association, Z24-X-2, was appointed in 1952 to explore the possibility of establishing standards of noise in industry. A full report[11] was scheduled for publication about November 15, 1953 giving most of the available data on the relations between hearing loss and noise exposure. As explained in a preliminary summary, no standards have been written nor criteria proposed, but trend curves have been developed which provide a means of estimating the effects on hearing of continuous exposure to steady noise. The application of these curves is limited, of course, by a number of factors which are discussed in the report of the committee.

It is generally agreed that high frequency noise is more harmful than low frequency noise of the same intensity. It is also known that damage will result from extremely intense sound even for short exposures, but permanent damage from even the loudest noises commonly found in industry will occur only as a result of exposure over a period of time.

There is probably a general rule that for more intense noises, more frequent and longer relief or rest periods are required if hearing is to be preserved.

In spite of the fact that "speed limits" for harmful noise cannot be set at present because of the lack of data in a very complex field, the tentative criteria establish a range of sound pressure levels above which there is possible damage. Pending future clarification, the engineer must set his own design goals with reference to hearing and be prepared to change them as more information becomes available.

Noise interferes with speech understanding when the noise energy in the frequency range between 300 and 4800 cps. approaches the speech intensity with most of the interference from 600 to 4800 cps. BERANEK[12] has defined speech interference level, SIL, as the average of the decibel levels in the three bands 600-1200, 1200-2400, and 2400-4800 cps. The SIL is a convenient but approximate method of estimating the amount of speech interference in a noise situation

and the amount of required noise reduction for effective speech communication. For a careful review of speech intelligibility in noise, reference can also be made to KRYTER.[7]

The following table gives SIL values for which communication is just possible at various speech efforts.

TABLE I.
SPEECH INTERFERENCE LEVELS AT VARIOUS VOICE LEVELS

SIL Average Noise Level in Three Octave Bands between 600 and 4800 cps.	Voice Effort for Just Understandable Speech
85 db.	Shout at 1 ft.
75 db.	Shout at 2 to 3 ft. Loud voice at 1 ft.
65 db.	Loud voice at 3 to 4 ft. Raised voice at 2 ft.
55 db.	Communication adequate for factory areas Communication adequate for business and secretarial areas

There is evidence, however, that speech intelligibility is greater in some cases than the SIL values indicate. This is probably true for speech at close distances and certainly for intermittent noise where speech information comes through between the noise peaks.

Referring to Fig. 1, the SIL for the pneumatic peen hammer is 95 db. and reference to Table I indicates that speech communication is impossible. A reduction of about 10 db. in the pressure levels in the three octave bands will make very loud speech understandable at close distances. The automatic lathe has a SIL of 82 db. and loud speech can be understood. For these noises, speech can be heard better than is indicated in the table.

The level of a warning signal which can be heard through broad band noise depends on the character of the signal as well as its intensity relative to the noise. A signal will be more easily recognized if its energy is concentrated in fairly narrow bands and if it is intermittent or changes pitch (for example a siren). In such cases, a signal can be heard even if it is 15 to 20 db. below the octave band noise level in any band above the 600 to 1200 cps. band.

III. How Noise is Produced

BEFORE discussing methods of controlling noise, it is helpful to consider briefly how noise is produced. For purposes of this discussion, noise can be considered as fluctuating air pressure which can affect the ear in an undesirable way. In some cases, the fluctuating pressure is generated directly in the air as in engine exhaust, combustion, or the turbulences of escaping air or steam and in high speed gas flow. More commonly, however, the air is caused to move by the vibration of solid objects or surfaces such as the housing or frame of a machine or solid objects on which work is being done. Sheet metal which is being hammered or sawed is a good example of a noise source. In many cases, the noise energy source may not itself radiate much sound, but its energy is transmitted by "solid" paths to the surfaces which radiate the noise. The intensity of the noise in the air finally depends on the space around the noise maker, i.e., it is affected by spreading, reflection, and absorption.

A. NOISE FLOW DIAGRAMS:

This noise production process can be analyzed by means of a noise flow diagram which indicates the sources of the noise, the various noise flow paths, and the radiating areas. Simplified examples of such diagrams are shown in Fig. 2 for a number of common noises. A machine or process will have a more complicated diagram, but it will consist of combinations of such elements. Once a diagram is made, the importance of the various sources, paths, and radiating areas can either be estimated from experience or calculated from tests in which sources may be stopped, paths may be interrupted or attenuated, or radiating areas may be enclosed, shielded or, in some cases, measured separately by means of close microphone locations.

It is very important to determine the source-path-radiator combinations which are the principal contributors to the noise. Noise levels are measured in decibels, which are logarithmic units representing intensity ratios. If a noise is caused by two sources, one of which is 10 db. below the other, complete removal of the weaker source will change the noise level by less than one decibel, and the change in loudness cannot be heard except under optimum conditions.

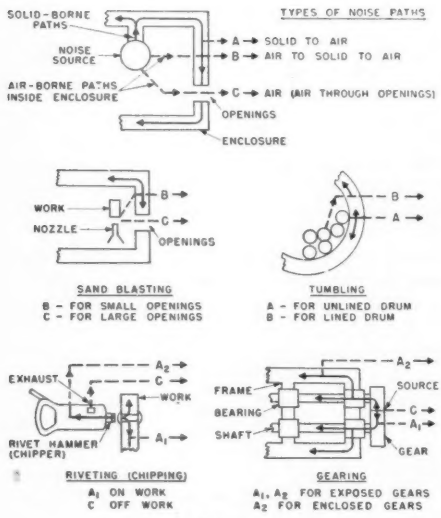

Fig. 2.
Examples of noise flow diagrams. Top—general case. Lower—diagrams of simple operations showing most important noise paths.

It is thus necessary to concentrate on the loudest or most intense contributor to the noise. The removal of one of two equal noise sources will reduce the noise level by three decibels.

B. NOISE SOURCES:

A list of common noise energy sources includes: (1) impacts, a sudden application or reversal of force, such as a hammer blow, tumbling operation, lost motion in parts of a mechanism, or even the jarring action of a toothed saw; (2) rapid reciprocating forces in the audible frequency range, such as the unbalance of a high speed shaft or the motion of a crankshaft; (3) friction, such as that in grinding, sanding, and squealing brakes or clutches; and (4) air disturbance involving rapid fluctuations in pressure or velocity, such as the hiss of escaping air or steam, combustion, air flow around bends or across edges which cause turbulence, high-speed turbulent flow, and sirens and whistles.

C. NOISE TRANSMISSION:

Noise energy may be transmitted from the source by paths involving the vibration of solid structures or by sound in air or by combinations of the two.

In Fig. 2, the relative importance of noise flow paths is indicated below the sketches. For sand blasting, the turbulent flow from the nozzle is the principal noise source. Openings through which work is inserted usually provide the most important noise paths unless the openings are small or the enclosure is made of thin resonant material. In tumbling, impacts on the drum cause it to vibrate and radiate noise. A lining such as rubber will practically eliminate this and give a lower total noise level since the noise path from the air inside through the drum has more attenuation. In pneumatic riveting or chipping, the work material, because of its resonances and greater area, nearly always radiates the most noise. The noise of the air exhaust is predominant only when the tool is out of contact. Radiation from the tool housing is usually not important. High speed gears are noise sources, but the noise radiated from the teeth is generally less intense than the noise which follows a mechanical path through the gears, shafts, bearings and frame. High frequency noise is radiated from the gear faces, but this is easily reduced by enclosing them. In general, it can be said that, except for pressure fluctuations created directly in air, nearly every noise flow has a solid borne path and noise reduction methods involving this path are often effective.

D. RESONANCES:

Resonances occur in vibrating systems when large amplitudes are caused by small exciting forces. Noise forces acting on a solid structure such as a plate produce amplitudes of motion which are limited by stiffness or inertia of the plate over most of the frequency range. Thus a heavy, stiff plate will vibrate less than a light flexible one. At certain frequencies, however, the stiffness and inertia forces cancel each other and larger amplitudes occur which are limited only by damping. Thus a lead plate has insignificant resonances because of its internal damping, while a brass or steel plate has pronounced resonances. Most vibrating systems have a family or series of resonances which starts with low frequency resonances which are relatively widely spaced on the frequency scale, and continues with more closely spaced resonances at higher frequencies. Resonant effects obviously increase the noise and can often be avoided in the low frequency region of

widely spaced resonances by changes in the frequency of the exciting force or in the stiffness or weight of the resonating part. Where this cannot be done, or where the resonances are closely spaced, the only recourse is increasing the damping.

E. RADIATION OF NOISE:

When a surface vibrates, the amount of sound given off will depend not only on the amplitude of vibration, but also on the size of the vibrating surface in relation to the frequency or wavelength of the sound. Information on sound radiation can be found in a standard textbook such as OLSON[13] or MORSE,[14] but it will suffice here to state that only large areas effectively radiate low frequency sound. The radiation effectiveness is related to the ratio of the dimensions of the object and the wavelength of the sound. The wavelength is inversely related to the frequency, being about 1.1 ft. at 1000 cps. in air and 11 ft. at 100 cps. Very little sound will be radiated from a source at 100 cps. unless it is several square feet in area, whereas at 1000 cps., loud sound can be radiated by a source a few square inches in area. Low frequency radiation from such a small source is low not only because of its small size, but also because it tends to radiate as a dipole, i.e., there is time for air to flow from one side to the other during one cycle of its vibration. Little sound pressure can be built up during this operation, so that a dipole is an inefficient radiator. Because of this effect, the radiation from a vibrating area will be increased at low frequencies if it is located in a larger stationary surface or baffle or is partially enclosed so that sound cannot flow from one side to the other.

The beaming effect or directionality of a source is also determined by the ratio of its size to the wavelength. A source several wavelengths in size radiates sound in a beam similar to an auto headlight beam, but a source small compared to a wavelength radiates in a spherical pattern like the light from a lantern. For this reason, high frequency noise such as a squeak or rattle can often be located by listening while a low frequency source is very difficult to locate. A similar effect is observed when a noise is screened by a wall or barrier. At high frequencies, where the barrier is large compared to the wavelength, it will cast an acoustic shadow, but at low frequencies, the sound will flow around the barrier almost as if it were not there. Fig. 3 illustrates the behavior of high frequency and low frequency noise in the presence of barriers or partial enclosures.

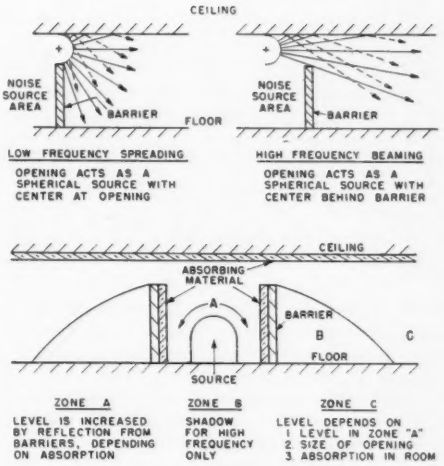

Fig. 3.
Noise flow past barriers used as partial enclosures.

F. REFLECTION AND ABSORPTION:

Noise levels in factory areas are greatly affected by reflection from surfaces of the room. Two general cases will first be treated, regularly shaped rooms and rooms with low ceilings. In the open air, the intensity decreases as the square of the distance from a spherical source, that is six decibels each time the distance is doubled. In an enclosed space, the sound reflected from the walls, floor and ceiling adds to the direct sound producing a higher sound level than in the open. This is shown by the curves for a single spherical source in Fig. 4 following HOPKINS and STRYKER.[15] Near the source, the direct sound predominates and the sound level decreases with distance, but farther away the reflected or reverberant sound is greater and alone determines the total sound level. Thus, for large spaces with reflecting walls, the sound level is quite uniform, except for higher levels close to the source. These sound fields are often called the direct sound field and the reverberant sound field. The level of the reflected sound is determined by the amount

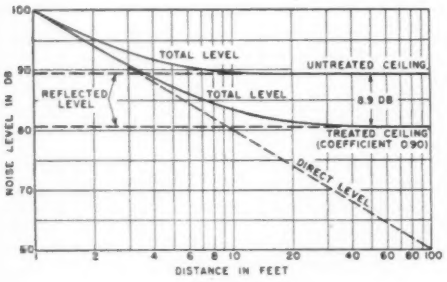

Fig. 4.
Noise levels related to distance from a simple source in a regularly shaped room, showing reduction due to absorption on ceiling. The total noise is the sum of direct and reflected noise. Total absorption untreated is 560 sabins for average absorption coefficient of 0.05. Total absorption treated is 3300 sabins with average absorption coefficient of 0.28.

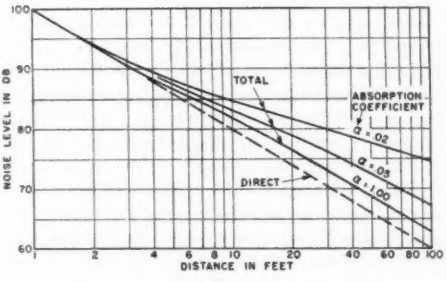

Fig. 5.
Noise level related to distance from a simple source in a room with a low ceiling, showing reduction due to different absorption coefficients of ceiling treatment. Ceiling height: 10 feet Absorption coefficient: 0.02 (after Sabine[17]).

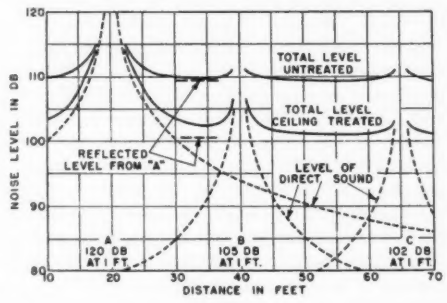
NOISE LEVEL IN DB
TOTAL LEVEL UNTREATED
TOTAL LEVEL CEILING TREATED
REFLECTED LEVEL FROM "A"
LEVEL OF DIRECT SOUND
A 120 DB AT 1 FT.
B 105 DB AT 1 FT.
C 102 DB AT 1 FT.
DISTANCE IN FEET

Fig. 6.
Noise levels from three unequal sources in the regularly shaped room of Fig. 4. Ceiling absorption reduces reflected level and permits operators to hear machines B and C above the reflected level of machine A.

of sound absorption on the room surfaces. The upper curves of reflected and total sound levels are for a room with hard, impervious surfaces, such as plaster, concrete, or wood, which reflect over 95% of the sound energy. Sound absorbing materials have been developed, however, which absorb up to 90% of the sound energy. The percent incident energy which is absorbed is called the absorption coefficient, and the amount of absorption is the absorption coefficient times the area of the surface in square feet, the unit being the sabin. The level in the reverberant sound field is reduced by such absorption, as shown in Fig. 4, but, of course, the direct sound which determines the level near the source is not affected.

Although the effect of absorbing material on the sound level in the reverberant field can be easily calculated, as will be shown later, rooms which have ceiling heights which are low compared to their other dimensions have quite different sound fields. Many factories have such low ceilings. SABINE[16,17] has shown that when the smallest horizontal room dimension exceeds 10 times the ceiling height, the sound level tends to decrease continuously with the distance from the source. In this type of space there is no constant level except quite close to the side walls. The variation of sound level with distance from the source in a factory with a low ceiling is shown in Fig. 5, which was taken from SABINE.[17] The upper curve represents sound levels with reflecting floor and ceiling, and the next two curves represent levels with sound absorbing ceilings having different absorption coefficients. It is seen that the sound level near the source is affected by the sound absorbing material, but the effect is small.

In most factory areas, there are numerous noise sources and the noise intensity at any point is the sum of the intensities from each source.[17] If there is considerable sound absorption in the factory, or if it has a low ceiling, the sound level at a considerable distance from each fairly widely-spaced source will be low (the lower solid line curve of Fig. 4 or any curve of Fig. 5). In these cases, the noise level near a source

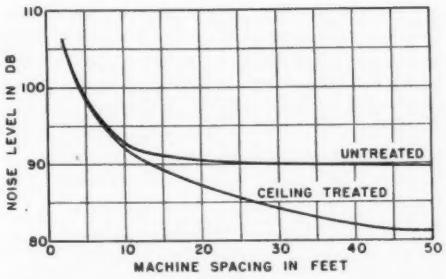

Fig. 7.

Noise levels at the center of 64 equally spaced machines showing effects of machine spacing and of absorption change from 600 to 3300 sabins.

will be caused by direct sound from that particular source and the worker can locate the position of a nearby noise quite well. In case there is not much sound absorption and the ceiling is not low, the noise from loud distant machines may drown out the direct noise from close but not so loud machines and the worker loses the sense of direction.

Fig. 6 shows levels of direct and total noise from three machines located in a large room as a function of distance along a straight line. The portions of the lines representing the levels of direct sound are curved because the distance scale is linear instead of logarithmic, as in Figs. 4 and 5. With low absorption, the upper curve indicates that the noises from machines B and C are practically drowned out by the louder noise of machine A. In the lower curve, the added sound absorption lowers the reverberant level from A so that B and C can be heard for several feet. The absorption not only reduces the noise level but allows workers on machines B and C to hear the operation of their machines.

When machines are closely spaced and approximately equal in noise output, the noise level tends to be uniform over the space and can be calculated[17] from the curves of Figs. 4 and 5. The noise level resulting from many closely spaced machines in a room with a high ceiling is not reduced much by absorption on the ceiling because the direct noise from nearby machines is much greater than the reverberant noise. The noise level is affected greatly, however, by the spacing of the machines as can be seen in Fig. 7, which shows the noise level (calculated from the curves of Fig. 4) in the center of a bank of 64 machines located in a square pattern in a room with a high ceiling. It is seen that an increase in spacing of machines from five to ten feet reduces the level by about six decibels, but a six-decibel reduction in level due to the treated ceiling cannot be obtained unless the spacing between machines is about 30 ft., which is of course an impractical spacing in most cases.

In many factories, closely spaced machines are used in rooms with low ceilings. In these cases, the direct noise from nearby machines is most important and the noise level is increased by reflection from the low ceiling. The noise level tends to be higher than in a room with a high ceiling, but this effect can be reduced by absorbing material on the ceiling. The added absorption also decreases the noise energy from distant sources as seen in Fig. 5. Even though absorption is of some value for closely spaced machines in a room with a low ceiling, the amount of reduction in noise level is not great unless the spacing between the machines is at least equal to the height of the ceiling.

Sound absorbing material in a factory has an important effect in reducing the reverberation time, thus causing a rapid decay in noise energy after an impact noise or between intermittent noise peaks. Reverberation time is defined as the number of seconds for a reverberant noise to decrease by 60 db. after the source is stopped. It can be calculated from the formula $T = 0.05\ V/A$, where T is the time in seconds, V is the room volume in cubic feet and A is the total absorption in sabins. The effect of a change in decay rate is shown in Fig. 8, where noise levels are shown for an intermittent noise pulse lasting 0.1 sec. and occurring once a second. The reverberation times of 5.5 and 0.88 sec. are those of the room of Fig. 4 with and without a treated ceiling. The noise peaks are reduced about nine decibels by the ceiling treatment, but the average disturbance to the ear is reduced a great deal more. The intermittent noise in the upper curve is smoothed out by reverberation so that it has the characteristics of a fairly steady high level noise. For the lower curve of Fig. 8, there are

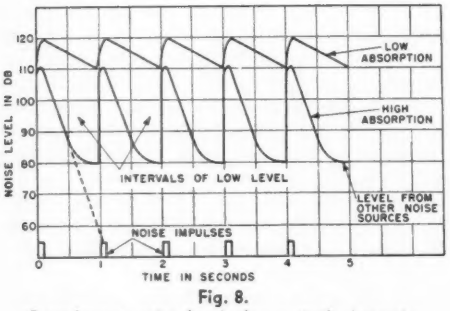

Fig. 8.

Reverberant noise levels for a single intermittent noise source. Intervals of lower noise level favor hearing recovery and permit speech communication. Low absorption reverberation time: 5.5 seconds. High absorption reverberation time: 0.88 sec.

intervals of low noise level during which the hearing mechanism can rest and this is probably very important in preventing fatigue and subsequent damage. There is also the possibility of transmitting speech or warning signals during the intervals of lower noise level. These low noise intervals due to absorption also exist for a worker in the direct sound field close to a machine.

IV. Methods of Noise Reduction

INDUSTRIAL noise reduction is a complex problem and methods of reducing the noise for a particular case depend on many factors. It should be emphasized that large reductions in noise energy are needed in every case. Changes of a few percent are insignificant with regard to hearing; a reduction to one-half of the energy is only three decibels and a reduction to one-tenth is ten decibels. Occasionally, a quickly made and inexpensive change will solve the problem, but in many cases much more radical measures must be taken. Since noise reduction is often expensive, it is important to determine how much is needed by reference to the section on noise level goals.

After looking for the obvious and easy solution, the next step should be an analysis of the problem. Since each problem is different, no general rules can be given and this section is organized according to the same headings as the preceding section, namely reduction of noise energy sources, reduction of noise flow, etc. In addition, a discussion of operational planning for noise reduction is included since this is an important overall approach to the problem. Estimates of the amount of noise reduction will be given whenever possible and these values will refer, unless otherwise stated, to noise levels in the 1200 to 2400 cps. band, since this is generally the most important frequency region for speech interference and hearing impairment.

A. Operational Planning:

Since noise in industry is becoming so important, planning to avoid or minimize noise problems should be done in laying out a new factory or modernizing an existing working area. Many dollars can be saved by planning which involves selection of work processes, location of noisy machines, and segregation of as many workers as possible from noisy areas. In planning a new factory, use can be made of the report "A Noise Survey of Manufacturing Industries"[18] to determine which machines are likely to produce excessive noise and how serious the problems will be. Although the spread of data of the summary curves is large, an intelligent guess can be made for expected noise levels from similar machines in the tables giving individual measurements. It is hoped that the small number of machine tool companies giving sound levels for their machines will be increased.

1. *Selection of Work Process:* Referring to the noise survey mentioned above, it is shown that the noisiest machines were those working on metal and that operations involving riveting and chipping were usually the noisiest, followed by saws, planers, etc. A general rule can be stated that operations involving impacts will be noisy, especially on large metal plates. A balance of noise reduction against costs of changes in work processing must depend on particular applications, and the following list of changes is given as a few obvious examples of alternate processes which cause noise reduction but without much regard to economic factors. This is a guide for the noise conscious production engineer who, no doubt, can list others which will be more practical for his application. In the future, some of the noisier processes may be quieted so that substitution will be unnecessary.

(a) Welding instead of riveting.

(b) Compression riveting instead of common pneumatic riveting.

(c) Pressing or rolling instead of forging.

(d) Grinding instead of chipping castings and welded joints.

(e) Electrically operated instead of unquieted pneumatic tools.

(f) Selection of less noisy types of conveyors.

(g) Avoidance of dropping hard materials during handling.

(h) Mechanical stripping of work from dies instead of air blast stripping.

(i) Low speed process machinery instead of high speed machinery.

(j) Substitution of materials; for example, fabrication of plastics is usually less noisy than sheet metal fabrication.

(k) Wide spacing between banks or rows of noisy machines instead of close spacing.

(l) Hot working of metals instead of cold working.

(m) Belt drives instead of noisy gears.

(n) Substitution of less noisy materials used in friction processes as in brakes and clutches.

Reference to the previously mentioned survey and experience in his field will enable the production engineer to recognize and avoid the use of noisy machines and processes when possible. Insistence on noise specifications in requesting bids for machinery will also aid in acoustical planning.

2. *Segregation from Noise:* A very important factor in acoustical planning involves placement of noisy machines and segregation of work areas having high noise levels so that only a few workers are exposed. Many cases are found in industry where the noise from one or two machines affects a large area where workers are engaged in less noisy operations. Restriction of noisy areas will be covered in more detail under reduction in noise flow, but stress should be laid on the location of noisy equipment in planning a new factory and in remodeling. Installations of absorbing material, changing work flow and installing walls are much less expensive in the construction of a new building than in an operating factory. If ceilings are high, noisy machinery should be walled into separate rooms with restricted openings into other work areas. For a large space with low ceilings, it may be adequate to group noisy processes at one end or corner of the space and to use acoustical material on the ceiling. Location of noisy equipment where partial enclosures will not interfere with work is also effective.

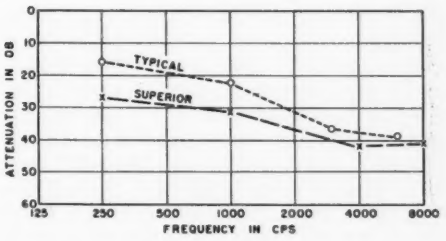

Fig. 9.
Attenuation of ear protectors (after Wheeler[19]).

Another aspect of segregation from noise is provision for reducing the time of noise exposure. In an inherently noisy process every effort should be made not only to reduce the number of workers exposed, but to make the process as automatic as possible so that workers can retreat to a less noisy area frequently for appreciable intervals of time. If this is not possible, the least that can be done is to provide that lunch and rest periods should be taken away from excessive noise.

3. *Personal Protection:* The use of ear protectors may be indicated under conditions where noise cannot be controlled by engineering means. Attenuation curves for typical ear protectors on the market are shown in Fig. 9, which was taken from Wheeler.[19] Nearly all are effective in the important high frequency region, but at low frequencies, where a tight fit is important, there is less need for attenuation. Contrary to the usual opinion, the understanding of speech in a high noise level is often improved by ear protectors. The noise is reduced as well as the speech and the speech signal-to-noise ratio is unchanged, but the levels at the ear are in a region where there is less distortion and better understanding. The principal difficulties in using ear protectors are sanitation and discomfort, but work is being done to overcome these handicaps. The problem of enforcing the wearing of ear protectors is usually considered more difficult than that for safety goggles or shoes, but alert management can popularize and enforce their acceptance.

B. Reduction of Noise Energy at its Source:

Prevention of noise at its source appears to be a promising method of noise reduction. It is often difficult or impossible, since noise energy may be an infinitesimal but unavoidable portion of the mechanical work done. One watt or 1/768 hp. of acoustical energy at 1000 cps. is a fairly loud sound and it is difficult to prevent this tiny acoustical loss when expending several horsepower in sawing, grinding, punching, etc. Noise production is sometimes, however, an unnecessary accompaniment of work and can be reduced by large amounts. Methods of reduction are discussed under various types of noise sources.

1. *Impacts:* Where a material is hammered, sheared, tumbled or peened, the impact is a necessary part of the work and is always accompanied by noise. Reduction at the source is difficult, but it will be seen later that noise radiation can be reduced by decrease in size of the work or by clamping it. If an impact can be made less sudden, i.e., the rise of force application made less rapid, the noise will tend to change from a sharp crack to a thud and will be much less objectionable. The reduction in high frequency components may amount to 10 to 15 db. In a punching operation, one portion of the die can be made to enter the work first and convert the process to a type of shearing action.[20] When punching involves a multiple die which makes several holes at one stroke, the die can be stepped to convert a single intense impact noise to several lesser noises. Prevention of unnecessary bounces from a hammer type blow also will be effective. In tumbling, impact noise on the containing cylinder can be decreased by suitable internal linings.

2. *Rattles, Lost Motion, etc.:* This type of impact noise can be classed as minor impacts and the remedies are fairly obvious. Proper inspection and maintenance; securing, stiffening, or damping of loose panels; and replacement of worn parts are effective. Elimination of rattles and lost motion prevents low frequency energy from being transformed into more undesirable high frequency energy. Significant noise reduction can be obtained which may be as great as 10 db.

3. *Unbalance Forces:* Alternating forces due to reciprocating motion or unbalanced rotation are usually in the low frequency region, but they often excite higher frequencies, especially when there is lost motion or rattling. Where the reciprocating motion is necessary to the work process, as in reciprocating engines or foundry shakeouts, reduction of the source energy, of course, is impossible unless the speed can be lowered. High speed rotating parts should be dynamically balanced. Except for these measures, noise reduction by other methods must be used for this type of force.

4. *Friction:* Considerable noise can be made by frictional forces in general and in grinding, clutches and brakes. Part of the noise in cutting of metals, wood, etc., can be classed as frictional noise. Motion along a contact surface creates force variation if the surfaces are not well lubricated and may proceed in jerks due to alternate stick and slip action. The frequency characteristic is rich in high frequencies usually because of resonances in the parts being excited. Clutches and brakes tend to squeal, grinding produces broad band noise, and other friction noises are of the squeaking and scraping type which have objectionable high frequency energy. Remedies include lubrication, substitution of materials in clutches and brakes (some rubber compositions are more prone to squeal than others), changes in shape of cutting tools and sharpening of tools which become noisy with wear. Gear noise is caused partly by frictional forces as well as variable forces at tooth impact frequency. Some improvement can be obtained by lubrication, substitution of helical or worm gears for spur gears, use of fibre or plastic gears, and reduction in speed, but attempts to refine the shape of well cut gears is usually not fruitful. Other methods to be discussed later are considered better solutions to gear noise. Although not much can be done in some operations such as grinding, alert and ingenious workers can often reduce frictional noise greatly or even eliminate it.

5. *Fluctuations in Gas Flow:* This category includes many loud noises principally because such fluctuations are noise (sound consists of pressure and velocity fluctuations) and when these exist there is no loss in coupling between a vibrating object and the air. In high velocity gas such as air or

steam, turbulence of flow and the resulting noise increase rapidly with air speed. This is the cause of much noise in the manifolds of reciprocating engines and is usually more intense than the noise of the explosions when the intake and exhaust are equipped with adequate mufflers. Reduction of flow speed, and streamlining in connection with sharp bends and obstructions in the air flow are helpful. In many cases, a partially closed butterfly valve will create noise due to turbulence. Use of a heavier or stiffer valve may help or two or more valves in series will reduce the gas speed around the edges of the valve. Many of these factors, however, are in the province of the machine designer instead of the factory operator.

Turbulence in the escape of compressed air or steam causes a loud hissing or roaring noise. When the air velocity is not being used, a simple muffler is effective. This, for outlets having small air flow, may consist of a can filled with steel wool or any other means of slowing down the escaping gas. Reductions of 10 to 15 db. are possible. When the air velocity serves a purpose, such as cleaning out chips, stripping, or moving parts, noise appears to be unavoidable at the present state of knowledge. The least that can be done is to keep the air flow at the minimum velocity necessary for the operation by using a reducing valve in the line.

Combustion produces noise as in the case of an oil or gas furnace or oven. Some of the noise is inherent in the design, but the operator should adjust the controls for as quiet an operation as possible.

High speed fans are usually noisy. Reduction in the speed of the blade tips, where the principal noise is generated, is a remedy. Noise reduction at the source is a problem of the fan manufacturer and reference to methods can be made to the journals of the heating and ventilating industry. For the plant operator, the remedy is in purchasing fans with a low noise rating and controlling the noise by methods to be discussed later.

Rapid interruptions or variations in air flow cause a siren type of noise which may be very intense. This is a serious problem in certain vacuum operations in the paper industry where perforations in a cylinder are moved past an air inlet. Some improvement can be made by reducing the speed of the siren or by redesign to smooth out the fluctuations.

6. *Miscellaneous Noise Sources:* There are, of course, noise energy sources which do not fit into the previously mentioned categories or are included in more than one. Noise caused by electrical or magnetic forces has not been considered, principally because it is generally not very intense and not much can usually be done about it by the plant engineer. If management is noise conscious, most noises can be traced to their sources and steps taken to reduce them. If the cause of a troublesome noise is mysterious, consultation with a noise specialist is advisable.

C. Reduction of the Flow of Noise Energy and Its Radiation:

This is a fruitful field for noise reduction because very powerful noise energy sources can exist without disturbance if the energy cannot flow from small inefficient noise radiators to larger areas which are efficient because of their size or because of their numerous resonances. A source can be isolated from its surroundings by prevention or reduction of coupling of solid borne vibration or by enclosing it behind a wall or cover in order to reduce airborne transmission. The most widely known example of noise flow reduction is the passenger automobile. Little is done about reducing the powerful noise source, but (1) intake silencers and exhaust mufflers reduce the flow of two noise components, (2) the fire wall is a barrier to keep the loud noise under the hood from entering the passenger space, (3) this under-the-hood noise is reduced in some cars by a pad of absorbing material, (4) transmission of mechanical vibration from the engine to the frame and body is reduced by flexible or compliant engine mounts and exhaust system hangers, (5) road noise is reduced by the tires and suspension system, and (6) damping is used on resonant body panels. These quieting measures have been very successful in the modern car and similar measures, although on a different scale, will be successful in industrial noise.

In the interruption and attenuation of noise energy flow, attention should first be directed to the main flow paths. This procedure can be illustrated by the simple case of gear noise. The noise sources are impacts

and friction at the gear teeth, but the teeth are too small to radiate much noise. If the gears are large, their face area is great enough to radiate considerable high frequency noise, but the principal noise path is through the shafts and bearings to the frame and other large area radiators. The noise from the gears and shafts can easily be boxed in, but it is usually much more important to vibration isolate the shaft bearing assembly from the outer structure.

In the following discussion, radiation is considered first, followed by solid-borne and airborne transmission, because the prevention of radiation is the end item in transmission problems and radiation effects are important in covers and partial enclosures.

1. *Radiation:* As discussed in the previous section, noise radiation depends principally on radiating area. For high frequency sound, the intensity is roughly proportional to the radiating area and for low frequencies, the intensity increases even faster with area. Thus the sound level decreases three decibels or more each time the radiating area is halved. Radiation effects are important at the lower frequencies because a source may be changed from a simple source, a good radiator, to a dipole, a poor radiator, or vice versa, depending on its size with relation to the wavelength. Such radiation from a vibrating plate or panel can be reduced at low frequencies by perforating it, but this is not often a practical solution especially when the panel has use in confining loud airborne noise. When a cover is placed over a noise source, it must be well isolated from vibration of the source because otherwise the cover, being larger, may radiate noise better than the smaller uncovered noise source. It is quite common to have an increase in low frequency noise level when a machine is enclosed or covered.

With regard to noise reduction from direct radiation effects, the size of objects which can vibrate should be kept as small as possible. For example, supports of piping or angle iron for a noisy machine may be better by 5 to 15 db. than supports using sheet metal; or two to one reduction in size of loosely supported sheet metal being punched may reduce the level by about three decibels. Clamping of such work close to the point of force of application is also very effective. Reduction of radiating area

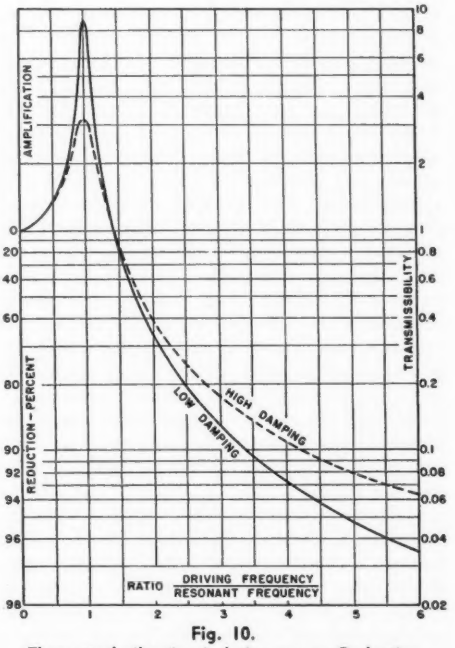

Fig. 10.
Theoretical vibration isolation curves. Reduction and transmissibility are based on the portion of the driving force transmitted through an isolator to a fixed foundation.

by clamping is also effective in the case of rods and bars when supporting arrangements can be used to localize the vibration to a small portion of the work, provided of course that the clamping arrangements are massive or stiff enough so that they do not themselves vibrate and radiate appreciable noise.

2. *Solid-Borne Transmission:* Since vibration is transmitted for considerable distances through nearly all solids without appreciable attenuation, reduction in solid-borne noise transmission involves interrupting the flow path by soft or flexible members or junctions. It is convenient to discuss first the case of vibration isolating mountings for machines although vibration of such parts as panels, subassemblies and covers will be shown to be more important in the later discussion. In the simple application of vibration isolation, a machine is mounted on compliant or flexible supports such as springs or pads of rubber. The weight of the machine and the springiness

or compliance of the mounts act like a filter which reduces vibration forces above a certain frequency as is shown in Fig. 10. This shows that vibration forces are amplified at frequencies below and near resonance, but are progressively reduced for higher frequencies. The amount of noise reduction in decibels is 20 times the logarithm of the reciprocal of the transmissibility. Thus a transmissibility of 0.5 is a reduction of six decibels and a transmissibility of 0.1 is 20 db. Damping resistance is advantageous in preventing large amplitudes near resonance when the machine is coming up to speed. There are many types of vibration isolators made commercially and the user can take advantage of the manufacturer's literature and design services. Fig. 11 illustrates some of the representative types.

A word of caution should be inserted about the effectiveness of simple vibration isolating mounts in reducing noise at the higher frequencies in which we are interested. In the first place, the theoretical curves of Fig. 10 show very high reduction for high frequencies, but this is not realized because the simple theory does not take into account (1) wave motion[21] in the mount, and (2) the fact that the supporting structure under the mount, such as a wall or floor, is not infinitely stiff to vibratory forces, but usually has many resonances which act to decrease greatly the calculated reduction in vibration transmission. Reductions of more than 30 to 1, or 30 db., may be difficult to obtain because of these effects. In the second place, vibration transmitted through the base of a machine and radiated as noise from a wall or floor is, in most cases, predominant in the low frequency region. Since industrial noise is commonly most objectionable at higher frequencies (above 600 cps.), reduction at lower frequencies by isolating mountings for machines is not as important as it is usually assumed. There are, of course, exceptions to this, but the main function of such mounts is to keep noise from being transmitted to other parts of a building or to adjacent rooms.

Other aspects of solid-borne transmission are, however, quite important in reducing objectionable noise, although reduction in the vibration flow paths of Fig. 2 is often in the province of the machine designer.

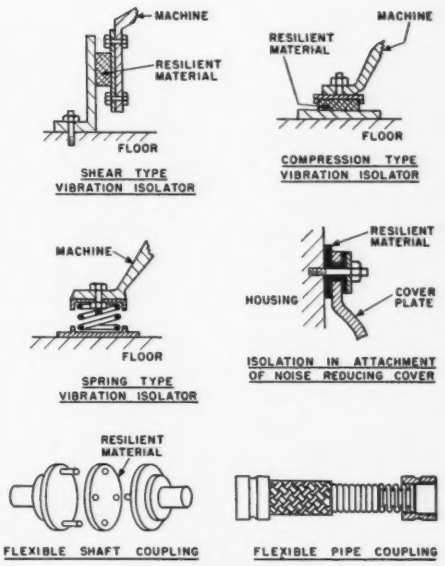

Fig. 11.
Devices for vibration isolation.

Any method of introducing compliance in solid-borne paths is effective. This may seem impossible to the mechanical engineer, but the compliance or springiness does not need to be great for reduction at high frequencies and very soft couplings or mountings which produce positional instability can be avoided. The terms compliance and flexibility are thus to be thought of as referring to relatively stiff components. The designer should analyze the problem to see whether noisy components can be mounted on subassemblies which are isolated by compliance from main castings or panels which will radiate noise. Belt drives are good for vibration isolation. Shaft couplings using leather or rubber-like materials are useful. Panels should be mounted on rubber gaskets and many other methods can be used for particular applications. Care must be taken so that a vibration isolator is not short circuited by mounting screws, rigid conduit, etc. Examples of compliant attachments are also shown in Fig. 11.

The plant engineer should use the methods discussed above whenever possible, but his attention also should be directed to interrupting vibration transmission to things attached to machines. Sheet metal ducts

should never be attached rigidly to a noisy machine since they provide excellent noise radiating areas. This applies to belt guards and other types of guards used for safety. When such devices are also used to contain airborne sound, they should be attached by resilient gaskets. For guards which can be "open" (expanded metal, for instance) resilient mountings are unnecessary since not much noise is radiated. Sheet metal or wood attached to conveyors can also be resiliently mounted to reduce noise. Of particular importance are panels or structures which enclose or partially enclose a noisy area. If these are rigidly attached where vibration energy is present, they may act as sounding boards and increase the noise instead of decreasing it. The amount of noise reduction obtained by such measures is widley variable depending on the relative importance of the particular noise path in the total noise output. Reductions of 10 to 20 db. for an individual path can often be obtained, however.

3. *Resonances:* The subject of resonance of solid objects must be considered. Single frequency resonance is relatively uncommon and can usually be detected as a pitched tone. The remedy is to detune the resonant part by stiffening it or changing its mass or to change operating speed to detune the exciting force. The more common case is the excitation of families of resonances by impacts, frictional forces, or other broad-band exciting forces. Simple detuning cannot be done because there are many closely spaced resonances. In some cases the whole family of resonances can be shifted up by the use of stiffeners or ribs. This is effective on plates and panels. Sometimes, the resonant member can be clamped so that it does not ring when struck.

An increase in the damping of resonant pieces is another method of noise reduction. It should be remembered, however, that damping ordinarily does not affect vibration transmission through a solid object unless the path is very long. It is useful mainly in reducing resonant vibrations which radiate noise. For light weight or thin materials, a spray coating of asphalt or tarlike deadening material such as that used in automobile panels can be used. As a general rule, the weight of the deadening material per square foot should at least equal the surface density of the panel. For steel panels thicker than about 10 to 14 gage, use of this material is obviously impractical. Laminated panels can be used to provide damping by friction between surfaces which tend to slide during vibration. For example, a steel ring loosely mounted in a groove in a streetcar wheel is a very effective noise reducer. In fact it is hard to clamp two parts together without destroying most of the resonant effects. In grinding, it is sometimes possible to hold two pieces together in order to reduce the noise due to resonances. Again the amount of noise reduction cannot be specified for this method, but in many cases it is very worthwhile.

4. *Airborne Transmission:*

(a) *Total Enclosures:* Noise in the air can be kept from spreading by almost any type of enclosure. The sound which is transmitted through an impervious barrier does so by causing it to bend flexurally. This is true even for massive walls. When the material is porous, however, sound travels through the pores without great loss. For this reason, sound absorbing materials of ordinary thickness (nearly all of them are porous) are of no direct use in reducing sound transmission, although their use is called for inside an enclosure to reduce the sound level which must be contained.

The transmission loss of walls, panels, and doors can be measured by standard acoustical laboratories and curves are obtained similar to those shown in Fig. 12. The transmission loss tends to increase with frequency although an average value for the region between 125 and 4000 cps. is often given for approximate use. The transmission loss increases slowly with the weight of the wall, so that large values are impractical in single walls. They can be obtained, however, by using double walls with an air space. In a relatively few cases, an extremely noisy machine or area can be totally enclosed to take advantage of these large noise reductions ranging from 20 to 45 db. Small openings will act as noise leaks, but these can be treated by the use of short ducts which are discussed later.

Two examples of total enclosures used in industry are shown in Figs. 13 and 14. Fig. 13 shows photographs of a decoring machine before and after it was enclosed by

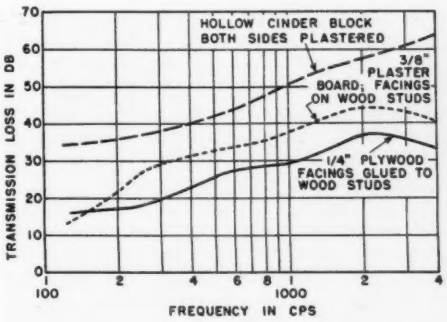

Fig. 12.

For a homogeneous wall, the sound transmission loss tends generally to increase with frequency. Increasing the weight per square foot of a given wall tends to increase its sound transmission loss.

½-inch plywood on 2- by 4-inch studs and lined with absorbing material. The outlet where the castings are dumped onto a metal conveyor consisted of an eight to ten foot lined duct. This treatment is reported to be very satisfactory. Fig. 14 shows an acoustical construction used to enclose a cutting machine. Openings for ventilation and product feeding are acoustically treated. The noise reduction[22] is reported to be nearly 30 db. in the 1000 cps. region.

Of more practical use in industry are enclosures with openings which range from less than a square foot for insertion of a part to be sand blasted to many square feet when access by crane or conveyor is needed. In such partial enclosures, the transmission loss of almost any impervious panel is more than enough (10 to 20 db.) because most of the noise comes through the openings. This is more of an absorption-radiation phenomenon and will be discussed under partial enclosures.

Covers over a noisy part of a machine are another useful method in noise reduction. Very often a particular area of one to four square feet radiates a large part of the noise and sometimes this can be covered. The possibility of such a solution can be checked by trial with an improvised cover such as an acoustically lined shallow wood box with edges padded for a fairly good seal. If this arrangement reduces the noise, a better cover can be made. The important design factors are: (1) an impervious barrier such as sheet metal, 16-gage or thicker,

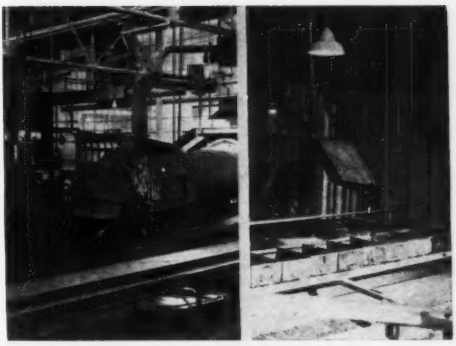

Fig. 13.

Decoring machine before and after installing a noise reducing enclosure. One panel is removed to show construction: ½-inch plywood lined with 1-inch Acousti-Celotex. (Photograph courtesy Cullum Acoustical Company, Inc.)

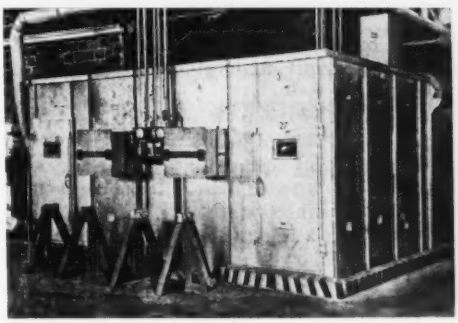

Fig. 14.

Enclosure for a cutting machine built with standard panels. A lined ventilation duct is shown on top at the right and the projections at the front are product feeding silencers. (Photograph courtesy Industrial Acoustics Company[22])

(2) rubber-like material to seal the edges and vibration isolated fasteners, and (3) absorbing material inside the cover to absorb sound and prevent buildup of noise in the enclosed space. The photograph in Fig. 15 shows such covers placed over noisy areas of a large diesel engine. These covers are easily removable for work on the engine. They are lined with one inch of high-density glass fiber material and are vibration isolated from an angle iron frame which is also vibration isolated from the engine. Noise reduction measured near the engine amounted to six to ten db. in the

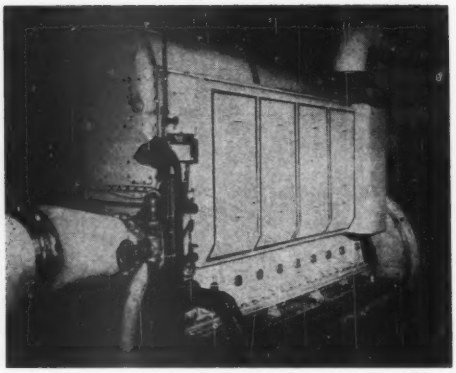

Fig. 15.
Noise reducing covers on a diesel engine. The covers are removable for engine repair. Black edges around panels are isolating rubber. Lagging on exhaust pipe in foreground also reduces noise (Ancell[23]).

octave bands above 600 cps. and was sufficient to permit understandable speech in this area.[23]

A type of cover which can be used over piping or ducts, consists of lagging with porous material and sealing the outside with a coating such as asphalt. The exhaust piping of the diesel engine in Fig. 15 was covered with a coating of asbestos for heat insulation followed by a 3-inch wrapping of mineral wool, the outer surface being sealed with asphalt. The wrapping damps out some of the pipe resonances, the resilient material reduces the vibration of the outer layers, and the coating eliminates noise flow through the porous material. Reductions of 15 to 20 db. can be obtained by this means for frequencies above about 1000 cps.

The problem of noise reduction in ducts is a specialized one to be handled by the supplier or installer. Absorptive duct liner is used and noise is thus progressively attenuated along the duct. Lined turns, absorbing splitters, and plenum chambers are part of this specialized work for high level noise in ducts. Noise vibration transmitted along the duct walls is customarily reduced by flexible joints or couplings. Some noise energy is transmitted through the duct walls especially near a noisy blower. Noise from such areas can be reduced by a short, separately mounted outer duct which is acoustically lined. When noise generated along a duct by high speed flow is too intense and the flow velocity cannot be reduced, the whole duct must be lagged or enclosed. Several engines with a common exhaust line may cause this condition. If the line must extend through a work area, it should be boxed in or lagged.

(b) *Partial Enclosures:* The term partial enclosure is used for noise shields and enclosures which have openings greater than than a few percent of their area. Included are various shapes from a panel on either side of a machine to box-type and tunnel-type enclosures. The sketches of Fig. 16 show how partial enclosures can be adapted to various machines and requirements of accessibility and work flow. As stated before, noise radiation from the openings is the principal path of noise flow from partial enclosures, since the transmission loss of the barrier is ordinarily at least 20 db. The

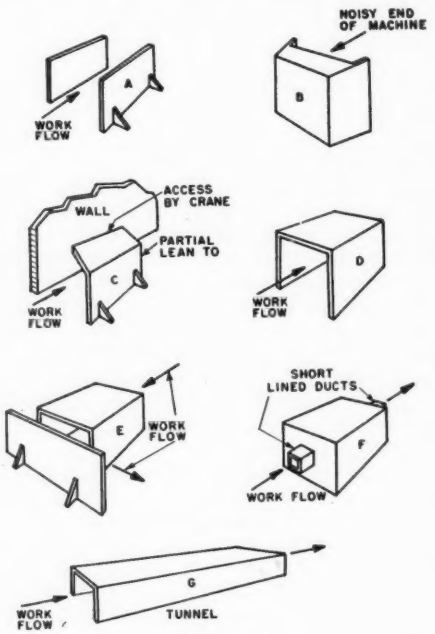

Fig. 16.
Types of partial enclosures arranged in order of their noise reduction. A, B, and C will be greatly improved by absorption on the factory ceiling. All should be lined with absorbing material.

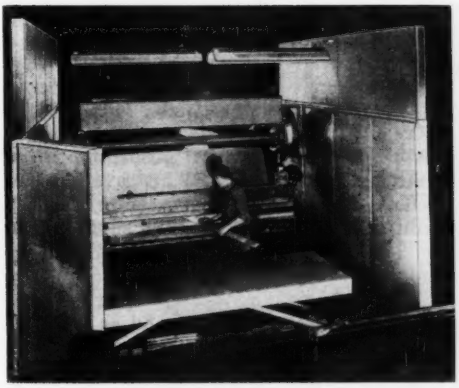

Fig. 17.
Partial enclosure for a metal forming machine built up from standard panels. Reduction of noise reaching the operator from his machine cannot be expected with this type of installation. He is protected, however, from other noises in the area and the noise radiated by his machine is reduced for other personnel outside the enclosure. (Photograph courtesy Industrial Sound Control, Inc.)

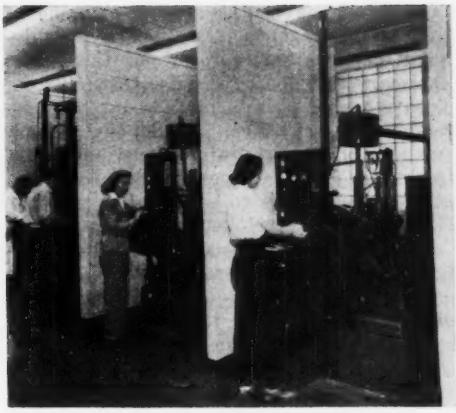

Fig. 18.
Absorbing panels separating engine test stands. Operators can hear the noise of their own machines and are given relief from noise of other machines during periods when their own machines are not in operation. (Photograph courtesy Celotex Corp.)

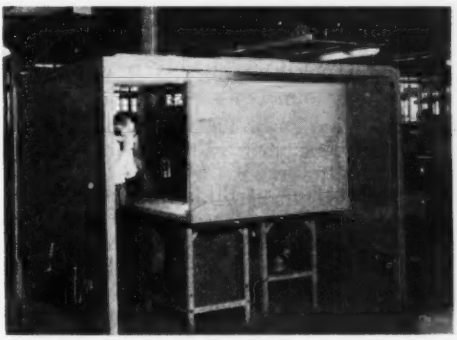

Fig. 19.
Partial enclosure used as a listening booth in telephone manufacture. Roof and the three side panels are lined with absorbing material. (Photograph courtesy Kellogg Switchboard and Supply Company)

effect on the reverberant or general noise level in the factory is not great unless the openings are small. For example, the open types at the top of Fig. 16 will reduce the reverberant level by only one to three decibels, but the tunnel may give up to about 15 db. Sound absorbing linings must always be used inside these enclosures or they will have little effect on the noise. The barrier material can be plywood, wall board, sheet steel or almost any impervious material with the requisite strength.

Partial enclosures are useful mainly in giving a shadow effect for workers otherwise in the high level direct field from a noise source. As illustrated in Fig. 3, this shadow effect is limited to the higher frequencies where the dimensions of the barrier are several times the wavelength. The extent of the shadow zone depends also on the distance from the openings and on the configuration of the enclosure and the absorption of the nearby room surfaces. The reduction in level of the high frequency direct sound will range from about three decibels for the partial enclosures in the upper part of Fig. 16 to about 15 db. for the tunnel.

Industrial uses of partial enclosures are shown in the photographs of Figs. 17 and 18. It is worth mentioning again that this type of enclosure does not protect the operator from the noise of his machine. In the engine test stands of Fig. 18 the operator can, however, listen more effectively to his machine since noise from adjacent machines is reduced.

Another use for partial enclosures is in providing a relatively quiet space for listen-

ing. Telephone booths are an example of this. In the manufacture of certain equipment, such as refrigerators or fans, it is necessary to inspect for noise. A tunnel enclosure over a portion of the conveyor system is very effective. In telephone manufacture, the short fairly open enclosure shown in Fig. 19 gives enough reduction at high frequencies to be useful.

D. ABSORPTION OF NOISE:

The most common use of sound absorbing material is a general or overall method of reducing noise in enclosed spaces. As discussed previously, the direct effect of sound absorption is the reduction of noise levels in the reverberant field at a distance from a noise source, but absorption will not decrease the level for workers less than five to ten feet from the source. The amount of reduction in noise level produced by adding absorbing material depends on the ratio of total absorption with and without the treatment. The total absorption in sabins is the sum of each area of the room surfaces in square feet multiplied by its absorption coefficient. Calling the absorption of the room A_1 before treatment, and the added absorption A, the reduction R in decibels will be approximately

$$R = 10 \log \frac{(A_1 + A)}{A_1} \qquad (1)$$

In the example of Fig. 4, a factory 80 by 40 by 20 ft. high was assumed. The surface area is 11,200 sq. ft. (ceiling, walls, floor) and the ceiling area to be treated is 3,200 sq. ft. An average absorption coefficient of 5% was assumed for the untreated surface area. This is higher than the coefficient for concrete, brick, etc., but it is a reasonable value for factory use since machinery and other irregularities scatter the sound and cause extra absorption. A_1 is then 11,200 x 0.05 or 560 sabins. For the absorbing material a coefficient of 0.90 was used. Many materials have coefficients as high as this between 500 and 2000 cps., the important range for industrial noise reduction. The added absorption is 3,200 x 0.90 minus 3,200 x 0.05 or 2720 sabins. The reduction is

$$R = 10 \log \frac{560 + 2720}{560} = 7.7 \text{ db.}$$

Actually, the reduction is a little greater than this because of higher levels near the source. The more accurate formula from Hopkins and Stryker[15] is

$$R = 10 \log \left[\frac{A_2}{1-a_2} \cdot \frac{1-a_1}{A_1} \right] \qquad (2)$$

where A_1 is the total absorption before treatment, A_2 is the total absorption after treatment, and a_1 and a_2 are average coefficients for the room surfaces in the two conditions. Where S is the total surface area

$$a_1 = \frac{A_1}{S} \quad \text{and} \quad a_2 = \frac{A_2}{S}$$

For our example a_1 is 0.05 and a_2 is 0.278, and the reduction is

$$R = 10 \log \left[\frac{3280}{1 - 0.278} \text{ x } \frac{1 - 0.05}{560} \right]$$

$= 8.9$ db.

The approximate formula (1) is accurate enough for most industrial work.

In very large factories, sound absorption in the air is not insignificant compared to the absorption at the room surfaces. It adds to the total absorption before treatment and thus reduces the effect of added absorption. (It increases A_1 in Equation (1). Air absorption depends on the humidity and is greater at high frequencies. For values to be used in calculations, reference can be made to Knudsen and Harris.[24]

It is seen that the added absorption does the most good when the original room surfaces are reflective and that the logarithmic factor makes absorption less and less effective as more is added. The limit for most practical installations is about 10 db. Although noise reduction by absorption is limited and is not effective close to a noise source, there are very many cases in industry where a reduction of five to ten decibels is all that is needed to correct an objectionable noise situation. Referring to the ordinate scales of Fig. 1 it is seen that 9 db. at 1000 cps. is a reduction in loudness of about 2 to 1. In other cases, absorption used with some other method will provide the needed reduction.

As an example of noise reduction due to ceiling treatment, Fig. 20 shows noise levels reported by Bonvallet[25] for measurements made before and after the installation of absorbing material on the ceiling. It is seen that the treatment lowered the noise level by four to nine decibels, a change from an

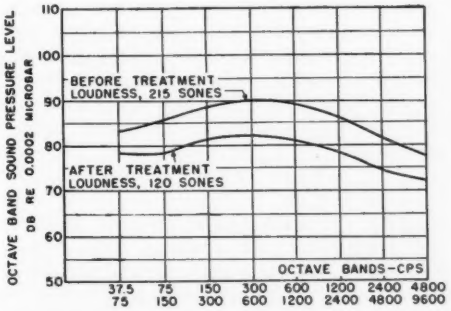

Fig. 20.
Noise levels in a machine shop before and after treatment of ceiling with sound absorbing material with air-space backing (after Bonvallet[25]).

Fig. 21.
Absorbing material used on ceiling and partial bays in a factory. (Photograph courtesy Celotex Corp.)

objectionable level to one where speech communication is possible.

In addition to the direct reduction in noise level, absorbing material has important indirect effects as discussed earlier. These were the "pushing back" of distant noise so the worker can hear his own machine, and the rapid decay of intermittent or impact noise which very effectively lowers its effect on the ear.

There are many types of sound absorbing materials, nearly all using porous material. Fibrous materials of vegetable or asbestos fibers or glass or mineral wool are used, and also hard but porous plaster-like materials with many interconnected pores. Perforations or other openings in the surface are often used to allow the material to be cleaned or painted without destroying its porosity effects. Loose mineral wool or bats may be covered with perforated metal pans or mounted behind other types of perforated panels. An air space between the material and the wall or ceiling improves the absorption at low frequencies. A suspended ceiling of this type gave the reduction over the wide range shown in Fig. 20. The user is referred to acoustical materials manufacturers for information on absorption coefficients, methods of application and costs. Fig. 21 shows absorbing material applied to the ceiling and also used to form pockets or bays in a factory space. This not only allows extra material to be used, but adds to the effectiveness of the treatment since the material is closer to the high-level direct sound.

Wall and ceiling application is often expensive, except in constructing a new factory, since production must be stopped and scaffolding erected. There are difficulties with overhead structures such as pipes, lighting fixtures, etc. In existing factory areas, space absorbers, often called functional absorbers, can be installed without much interference with production. Space absorbers are suspended in the upper part of a room usually on wires. One type on the market consists of two by four feet flat baffles of glass fiber board covered with a plastic film so that they can be easily cleaned. It is expected that other types will soon be available commercially. The amount of material for a given absorption at practical spacings is usually greater than the amount required if placed on the ceiling, but the convenience of installation may still be an advantage in many cases.

V. Simple Methods of Noise Reduction

IN NOISE reduction work and in surveys of industrial noise, acoustic engineers of the Armour Research Foundation have seen many noise problems. A number of these had obvious and practical solutions and could be handled easily and at low cost. Ten of these are given below as practical examples. It must be remembered, however, that many noisy operations are difficult and should have expert assistance for satisfactory solution.

1. Spent air is a common noise source in many factories. Where this air serves

no useful purpose, it can be exhausted through simple silencers which are available commercially. A metal box filled with steel wool is often adequate. Otherwise the exhaust air can be piped outside the room.

2. Tumblers and ball mills usually can be enclosed, with hinged panels for accessibility.

3. A sand blast unit with openings for manual insertion of objects was observed to produce much noise. A housing of heavier, more soundproof material with provisions for covering the openings when not in use would have greatly reduced the noise.

4. Air-operated tools are usually noisy. Mufflers can and should be provided by the manufacturers. Workers often wrapped such tools with burlap and held them with a hand over the exhaust opening to reduce the noise.

5. Many operations involve machines which operate unattended for considerable periods and these are often particularly suited for rather complete enclosures. A type caster is one example which was observed where a relatively small enclosure would have reduced the clatter from over 90 db. to less than 80 db. in the important high frequency bands. Another was a noisy rubber chopper or granulator which was enclosed to give reductions of more than 20 db. in the high frequency bands.

6. A paper bag machine produced a loud screech at irregular intervals. It was found that a torsional resonance of a shaft was excited by friction of the paper. Changes in certain dimensions resulted in elimination of the noise.

7. Chipping of castings causes excessive noise. A remedy is to move the castings by a conveyor and do the chipping in an acoustically lined tunnel over it. Workers doing the chipping must wear ear protectors, but other workers are protected from the noise by the tunnel.

8. Foundry core draw vibrators are noisy, but the newer machines have moving parts which vibrate at lower amplitudes and lower frequencies and thus reduce the noise.

9. Some woodworking operations are enclosed by metal and canvas shields as part of exhaust systems for removal of chips and shavings. Substitution of a more complete enclosure of metal or wood is indicated for noise reduction.

10. In the operation of some automatic screw machines, it has been observed that much of the noise is due to rattling of the stock in loose or oversize guides. Noise reduction can be done by better maintenance and supervision to insure the use of proper guides.

VI. Conclusions

SINCE IT IS expected that the noise problem in industry will in the future receive even more attention than at present, work toward a satisfactory solution needs cooperation between management, safety engineers, machine designers, and acoustical engineers. Since practical noise reduction is generally a complicated process and involves costs and associated compromises, no single method can be recommended and it is necessary to take advantage of any possible methods. For this reason the preceding discussion has included the whole noise process from the source through various transmission paths to radiating areas and absorption and reflection effects. Each noise problem must be analyzed to determine how much the noise should be reduced and what phases in the noise process lend themselves to economical noise reduction. It is hoped that the information presented will enable factory personnel delegated for noise reduction work to find a satisfactory solution for many noise problems.

In addition to work on existing machines and processes, management should help the cause of noise reduction by requesting noise spectra as part of the specifications on new machines, planning of plant layout and design, and selecting work processes with noise effects in mind. In the latter phase, expert advice will be valuable. In the planning stage, an acoustical engineer with experience in industrial noise can even estimate probable noise levels which will occur in a new factory.

Industrial management can also help in encouraging research work on some of the important unsolved noise problems affecting industrial noise. A number of these are listed below:

1. The establishment of hearing damage criteria is an important problem. Exploratory work on possible standards has been done by Committee Z-24-X-2 of the American Standards Association, and it is hoped

that engineering standards will evolve. There are, however, many phases where much more research is needed.

2. The effect of impulse noises on the ear is a field of study which is important to industry but which has not been well explored. In fact, the physical measurements necessary to characterize such noise with respect to hearing are not well known.

3. The subject of ear protectors has been investigated and is still being studied, but there is need for an early development of engineering specifications for their industrial use.

4. A study of work processes to find modifications or substitutions which will reduce noise is well worth-while. An obvious example needing a less noisy method is riveting, and another is the use of air to remove chips or to strip parts from dies.

Although there are unsolved problems in the field of industrial noise reduction, it is believed that there is sufficient engineering information to handle, in some fashion, most cases of excessive noise. As additional information becomes available, more exact and economical solutions will evolve and safety engineering with respect to noise will become more routine and widely accepted.

VII. Acknowledgment

ALTHOUGH much of the material on reducing noise is general in scope and was taken from many sources, the accumulated experience of co-workers at Armour Research Foundation has been valuable in the application to the industrial field. Acknowledgment is given to this contribution and especially to H. C. HARDY and D. B. CALLAWAY. G. L. BONVALLET'S experience in making noise surveys of industry has also been most helpful.

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INDUSTRIAL noise is perhaps the most serious environmental health problem confronting American industry today. It has given rise to a new type of compensation claim based on hearing loss, even though no wage loss has resulted. In state after state, such claims are multiplying. Suits are piling up. Claims against one New Jersey company total $5,000,000. The Wisconsin Supreme Court has ruled that loss of hearing, alone, is basis for compensation.

—From "Noise Costs Money" by C. RICHARD WALMER, M.D., in *Medical Advance*, December, 1953.

ADVANCES IN THE PREVENTION OF

Occupational Skin Disease

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ALTHOUGH occupational skin disease was described as early as 400 years ago, the great contributions in this field have been made in the last 50 years. Dermatology has been a most active force in providing industrial medicine with knowledge concerning the recognition and diagnosis of the occupational skin diseases. Today, however, we are faced with a persistently high incidence of these diseases, and the importance of preventing them must be constantly emphasized.

By experience we have learned that occupational dermatitis can be prevented, both by efficient engineering control methods and by personal protective measures. It is the latter preventive measures, however, which form the basis of this discussion.

During the past 10 years, several significant advances in dermatoses prevention have taken place in laboratory and field work dealing with the following: (1) Evaluating techniques for preventing occupational and non-occupational dermatitis. (2) Educational methods. (3) Protective clothing. (4) Industrial cleansers. (5) Protective ointments.

Evaluating Techniques

EACH DAY new materials and products capable of injuring the skin or of causing systemic damage to the human body are being introduced by our industrial development. To prevent undesirable effects among the handlers and users of these compounds, some manufacturers of chemicals, rubber, fabrics, cosmetics, among other products, are conducting toxicity evaluating tests on lower animals (guinea pigs and rabbits), humans, or both.

Investigators have frequently employed percutaneous (contact) exposure methods in lower animals to evaluate the primary irritant and/or the acute and delayed systemic effects of certain substances. The percutaneous toxicity evaluations are helpful in providing information regarding the acute and delayed toxicity caused by certain materials. The procedure can also be effectively used to determine the primary irritant effects of compounds upon animals. By using these methods, it is often possible to predict an effect upon man, but it must be emphasized that the results observed in animals cannot always be applied to man because of occasional reversals of action.

Sensitization studies employing the guinea pig have also been used in an effort to evaluate the allergenicity of certain compounds. These tests also can be of assistance, but by no means can we rely upon them in all instances because the intracutaneous technique in guinea pigs possesses certain deficiencies which limits its use in detecting sensitizers other than those of potent nature. For example, (1) the guinea pig is generally less sensitizable than man, (2) the animal strains are not uniformly susceptible, (3) the histologic changes in guinea pigs are not strictly analagous to the allergic contact-type lesion in man, (4) the problem of anaphylaxis in animals creates difficult interpretation, and (5) the use of uniform dosage fails to consider that a greater concentration of one substance may be required to induce sensitization than would be found from the same dosage of another substance.

In human testing, the prophetic patch test introduced by Schwartz and Peck is a method of evaluating the irritant or sensitizing capacity of a substance, first by patch testing and then by actual use. When executed properly the test can be a useful procedure, but over the years investigators have made the following interesting obser-

vations regarding the procedure. Henderson and Riley, for example, showed statistically that 200 subjects as advocated in the test is actually an inadequate test group. Others believe that the 24-48 hour application of the test material is insufficient and should be replaced by more prolonged contact such as wearing the material for an extended period of time. Still others prefer repetitive testings covering a several day period.

Despite these problems which accompany the use of the prophetic patch test, better testing methods have yet to be generally used and accepted. It is probable, however, that improved techniques will be established as more investigators become interested in the procedure.

The real point of emphasis regarding evaluating techniques is that less contact-type dermatitis will be incurred by workmen and consumers as more manufacturers utilize these methods before introducing new products.

Educational Techniques

IN IDEALLY conducted industrial hygiene programs, educational methods are vital. In such a program, new employees, after having been thoroughly examined, are placed in jobs which will not over-tax their physical or mental capacities. They are instructed in detail regarding the nature of their work and the hazards, both chemical and mechanical, which may be encountered. Environmental and personal control methods must be explained completely. In addition, the workmen are constantly reminded of the possible hazards by conspicuous placards in the work area and by short but informative safety meetings. It is obvious that a thorough job evaluation of the plant must be made before such information can be imparted to the employee.

In the past, workmen often hesitated to report a dermatitis for fear of losing their jobs, but today a skilled physician can observe the affected workmen, arrive at a diagnosis, establish the cause, and then initiate the methods for preventing other cases.

Protective Clothing

TWENTY YEARS AGO little thought was given to the need for protective clothing and still less to its selection or design. A decade of progress now permits us to select protective garments of rubber, plastic, leather, cotton, or other materials, depending upon the requirements. We are able to purchase clothing which can protect against chemicals capable of entering the skin and against the extreme exposures of heat, cold and moisture. A protective clothing made of synthetic fiber is now on the market and is said to resist acids, alkali, and mildew and, in addition, has better wearing and anti-snagging qualities.

One of the past difficulties associated with protective clothing has been the lack of attractive design, but the clothing now available provides little basis for such complaints and is, therefore, readily worn. Furthermore, our observations have shown that the use of protective clothing is best controlled in those plants where the clothing is furnished, serviced, and laundered by the plants.

Industrial Cleansers

CLEANLINESS is still the keystone in the program of prevention, and good cleaning compounds are closely allied to cleanliness. There is a large selection of industrial cleansers on the market, but confusion still exists in some plants regarding the choice of these agents. The two most popular forms of industrial cleansers are liquid and powdered forms. Liquid types can be made from sodium and potassium soaps, sulfonated vegetable oils, or the newer detergents, all of which are efficient for those workmen who do not experience intense soiling of the hands and arms. On the other hand, powdered cleansers can be of light or heavy duty type, the latter being more appropriate for tenacious soiling. Some of the heavy duty cleansers contain abrasives such as pumice, sand, ground corn cobs, or wood chips, and not infrequently some of these abrasives will produce rather than prevent dermatitis. Corn meal is an acceptable abrasive that has the disadvantage of clogging drain pipes. Many of the above cleansers also contain wetting agents and water softeners which help to improve the detergent qualities of the soap.

Antiseptics such as hexachlorophene have been introduced into industrial cleansers and are particularly advocated for certain workers such as food handlers and meat

packers and for those exposures where bacteria often play a secondary role in an occupational dermatitis.

Other cleansers well known in the past but which are now being used in fairly large quantities are the waterless type. These agents are usually of liquid or semi-solid greasy consistency and effect cleansing by (1) their solvent content, or (2) their alkali content. Recently another waterless type cleanser composed of wetting agents and possessing a neutral pH has been introduced. These waterless cleansers can efficiently remove stains, dyes, oils, and greases from the skin. Indeed, some of them are advertised as being capable of removing paint, lacquers, and plastic from the skin.

Before we can advocate widespread use of these materials, however, complete laboratory and field evaluations of the various waterless hand cleansers should be made.

Protective Ointments

IN SELECTIVE cases, protective ointments or barrier creams may be the best method of preventing occupational dermatitis. As a general rule, however, these agents are less efficient than other methods of protecting the skin.

In view of the known inadequacies regarding protective ointments, several investigators have become interested in this field, and some noteworthy contributions have been evidenced in the past few years. For example, DRS. RUCH and FOERSTER of Milwaukee have shown that tar and pitch vapors, fumes and dusts are less able to contact exposed portions of the body if a barrier similar to calamine lotion is applied to the skin. Even more important, their work showed that conventionally-used ointment bases of animal or mineral fat actually facilitated contact of the ointment-covered skin with tar and pitch vapors, dusts and fumes.

A great amount of interest is being shown in the use of silicones as barrier agents. There are several of these protective ointments on the market, but as yet we have not been able to determine the amount of laboratory and field evaluation which has preceded their introduction. The fact that the silicones are inert and capable of repelling water and heavy oils strongly favors their use in protective ointments. It is quite probable that some of these ointments will be valuable in protecting the skin against water-soluble agents.

This review briefly represents some of the advances in prevention which have occurred over the past decade. They indicate a steady trend in progress and serve to encourage those of us who devote our efforts toward improving industrial hygiene. Whenever we develop new methods to prevent occupational disease, it is natural to experience the satisfaction which accompanies progress.

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Experiences with Unusual Materials and Operations

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IT IS NOT our intention to describe in detail any of the routine or development procedures in use by the Industrial Hygiene Group at Los Alamos, but rather to sketch for you some of the actual experiences we have had with the handling of some elements and compounds not routinely encountered by everyone.

First, many radioactive materials common to various Atomic Energy Commission installations, and only to them, have been omitted because almost all information concerning them is available to those interested; second, certain substances are not mentioned because of their use in conjunction with classified materials or processes. A strictly hypothetical instance of the latter might be the use of irium with plutonium, a situation which obviously precludes any discussion of the interesting industrial hygiene problems presented by irium.

Arsenic

EXPOSURE to arsenic and its compounds occurs during operations utilizing arsenic oxide, arsenic sulfate and arsenic metal. These are used as powders of normally 100-170 mesh and present no dust problems. However, in heating to temperatures of 300-600 degrees centigrade, high air concentrations are produced. Occasionally, metallic arsenides are formed; these materials can react with the moisture of the atmosphere to produce arsine. Arsine production is apparently a function of the relative humidity and at Los Alamos is a problem only during the winter when relative humidities in excess of 20% are common.

Arsenic dust and vapor samples are collected with electrostatic precipitators, filter papers and large impingers. Arsine samples are collected with two large bubblers in series containing sodium hypobromite. Analysis is carried out by the well known molybdenum blue reaction after intermediate generation of arsine.[1] Levels of one part per million can be measured by drawing air through filter paper impregnated with mercuric chloride at a rate of 20 liters per minute.

Control measures consist in completely enclosing all processes involving arsenic and exhausting working areas at rates above normal minimum standards.

Barium Nitrate

BARIUM NITRATE has been micropulverized at Los Alamos. The permissible concentration recommended by the American Conference of Governmental Industrial Hygienists for soluble barium compounds is 0.5 milligrams per cubic meter calculated as barium. Most of the exposure data is derived from studies on accidental ingestion; little is known regarding the effect of inhalation aside from limited animal experiments.[2]

Air samples are collected with a midget impinger containing dilute nitric acid. Analysis is carried out by co-precipitating potassium permanganate with barium sulfate and comparing the color of the precipitate with standards. The results from approximately 100 analyses showed that the average air concentration is well below permissible limits; however, concentrations as high as 3.0 milligrams per cubic meter have been found during shoveling of barium nitrate.

Micropulverizing is completely enclosed and adequately exhausted; otherwise, it

This document is based on work performed at the Los Alamos Scientific Laboratory under the auspices of the Atomic Energy Commission.

would be necessary for workers to wear approved dust respirators.

Boric Acid

BORIC ACID is handled in grinding and mixing operations. The greatest difficulty encountered by the Industrial Hygiene Group with this material is the tendency of most workers to consider it completely harmless. A number of cases of poisoning, chiefly from accidental ingestion of boric acid, have been reported in the literature, and the material, therefore, must not be considered completely innocuous.[3,4] No permissible value for boric acid dust has been established, but every effort is made to keep air concentrations below 2 milligrams per cubic meter.

Boric acid dust is collected in distilled water using a large impinger at a flow rate of one cubic foot per minute. Analysis is carried out by sodium hydroxide titration in the presence of mannitol using a glass electrode.[5]

All operations involving boric acid are adequately ventilated. In processes involving boric acid solutions, rubber gloves are worn since boric acid is readily absorbed through the skin.

Another boron compound of interest to us is trimethyl borate, used in experimental scintillation counting. Air may be sampled for trimethyl borate using distilled water as a collecting medium, since the compound hydrolyzes with extreme rapidity. The only control measure instituted in connection with this material is the use of activated charcoal respirators; this is an obvious precaution since a methanol hazard may come about by hydrolysis of methyl borate.

Beryllium

BERYLLIUM metal has been processed in the shops and metallurgical laboratories and various soluble salts of beryllium have been prepared and handled in the chemical laboratories. The largest number of men are exposed during machining of beryllium, although the most difficult processes to control involve the use of powdered beryllium and soluble beryllium compounds.

Air samples for beryllium dust are routinely collected on a Whatman #41 filter paper at a rate of 20-25 liters per minute. Air samples are collected in the workrooms to determine the average 8-hour exposure. In certain locations automatic filter paper changers are in use; these collect separate samples hourly. In laboratories where soluble compounds are handled in completely enclosed systems and mounted in well ventilated hoods, air samplers are run continuously for one week to reveal accidental generation of beryllium compounds in the air.

Analyses are conducted by the morin fluorometric method of Sax and Kramlich[6] after complete ashing of the sample. In our experience, the sensitivity of this method is entirely satisfactory, although the method is not dependable much below a total sample content of 0.05 micrograms of beryllium.

Results of approximately 1000 air samples reveal that the average concentration has been kept below the Atomic Energy Commission's permissible level of two micrograms per cubic meter. Air samples collected during isolated infrequent processes where the workers wear adequate protective equipment show results considerably above this figure. It is absolutely necessary to provide adequate ventilation for any process involving beryllium or its compounds; if an exception is made for a single operation, efficient dust respirators must be worn.[7]

Columbium

COLUMBIUM (now known as niobium) has been used in our metallurgical laboratories; the metal has been machined and it is incorporated in welding rods for use on certain stainless steels. The quantity of the work has been small and no heavy exposures have been encountered.

Because of the known toxicity of vanadium and the possible chemical similarity between columbium and vanadium, it is anticipated that columbium may possess some toxic properties.[8] No experimental work has been reported that would supplement this belief.

Heavy exposures to columbium should be avoided and certainly air concentrations should not exceed a probable value of 15 milligrams per cubic meter.

Lanthanum

LANTHANUM metal has been vacuum-cast at Los Alamos. On heating, the metal

forms the oxide very readily, creating a potential fume hazard.

There is little data on the physiological effects of lanthanum or its salts; recent experience in industry with the oxide fume and dust indicate that workers occasionally complain of headache and nausea after exposure.[9,10]

No air samples for lanthanum have been collected at Los Alamos, emphasis having been placed on adequate local exhaust systems for control.

Lanthanum[140] is a radioactive isotope used occasionally at Los Alamos for experimental purposes. The properties which make it useful for these purposes (strong beta emission and forty hour half-life), also make it ideal for measuring the fashion in which air-dispersed materials in general are distributed.

In order to determine this distribution about the points from which the material originates, air samples for beta counting are collected with a high volume sampler on flat filter paper at 50 cubic feet per minute; the particle size of the radioactive dust is determined with a cascade impactor by beta counting and determining mass median diameter. The intensity of radiation is indicated by leaving flat metal trays, coated with a non-drying alkyd resin, exposed at various points and mounted five feet above the ground. These trays, 96 square inches in area, are radioautographed using x-ray film.

Our results indicate that no measurable amount of this radioactive material has appeared at any populated part of Los Alamos, and that the dust we have collected is of respirable size and could conceivably constitute a hazard.

Tantalum

TANTALUM metal is machined at Los Alamos; the hazard involved, however, is not the tantalum itself but rather the carbon tetrachloride used extensively as a cutting lubricant.[10] Experimental work by Carney[11] showed tantalum metal embedded in the abdominal wall and bones of dogs had caused no physiological disturbance.

Air samples for carbon tetrachloride are collected in the breathing zone of the operator by drawing the air through silica gel at the rate of three liters per minute. Analysis is carried out by titrating for chloride ion after decomposition of the carbon tetrachloride molecule.

Careless use of carbon tetrachloride gives air concentrations ranging from 50-105 parts per million; careful use of carbon tetrachloride, allowing the excess to drop on to Speedy-dri in the pan of the machine, reduces concentrations below 50 parts per million.

It may be of incidental interest that no satisfactory substitute for carbon tetrachloride has been found.

Thallium

SEVERAL thallium compounds have been used in experiments creating both dust and fume. On heating, the metal oxidizes rapidly to brown oxide fume, our most serious exposure.

Thallium is well recognized as a toxic substance and is similar to lead in its chemical properties.[12] Air samples for thallium fume are collected with the electrostatic precipitator; analysis is made with the polarograph by the technique of Winn and Nelson.[13]

It is obviously necessary to exhaust efficiently all operations involving thallium and its compounds.

Thorium

THORIUM metal has been handled by many fabrication techniques. When heated, thorium metal oxidizes rapidly in the air and produces considerable dust.

Thorium is, generally, a radioactive poison rather than a material of any great chemical toxicity. The internal radioactive hazard is primarily due to the alpha activity of thorium and its daughter products; the inhalation of thoron gas is probably a minor factor as far as internal radiation is considered. The Health Division at Los Alamos has adopted a temporary tolerance level of 66 disintegrations per minute per cubic meter. The external radioactive hazard is due to the beta and gamma radiation from thorium and its daughters. Film badges are worn by all exposed personnel and our experience in using this mode of measurement indicates that the external radiation hazard is very small.

Air is sampled for thorium dust with a Whatman #41 filter paper at 25 liters per

minute. The concentration is determined by alpha counting; the particle size is estimated with a Casella cascade impactor. Results of air samples indicate that there is a potential hazard, although only breathing zone samples collected during certain heating operations were above the adopted tolerance, some of these running as high as 3350 disintegrations per minute per cubic meter. An ulta-filter dust respirator is worn during all such operations.

As far as control measures are concerned, film badges are worn during all operations, in addition to adequate local ventilation and wearing of approved ultra-filter dust respirators. After processing, all metal pieces are oiled to prevent oxidation and are stored in well-ventilated hoods.

Uranium

A UNIQUE item of interest with regard to normal uranium is a peculiar fume which arises during the accidental burning of uranium chips and turnings during machining operations. Cascade impactor samples of this fume reveal that the mass median diameter is approximately 0.3 microns and fluorometric analysis shows that breathing zone concentrations are occasionally 50-150 times the accepted tolerance level of 50 micrograms per cubic meter.

This fume, although chemically an insoluble uranium compound, causes a rapid increase in the urinary uranium of exposed personnel, thus resembling the so-called soluble uranium compounds. It is possible that this effect is a function of particle size.

Chloromaleic Anhydride

THIS is an organic liquid used routinely in the formulation of an adhesive. Large areas are exposed during application of the adhesive, making control of the vapor more difficult. It is a severe lacrimator and causes profuse watering of the eyes at air concentrations above five parts per million; several workers have found it necessary to report to the nurse for relief from this condition. It has been reported by Carpenter and Smyth[14] that maleic anhydride is an acute eye irritant to rabbits and it is only logical to assume that chloromaleic anhydride would be at least an equal offender.

Air samples are taken with a hand-operated midget impinger because of a fire hazard associated with the operation involving chloromaleic anhydride. The air is drawn through ethanol at a rate of two liters per minute. Analysis is carried out by titration for chloride ion following decomposition of the sample.

Adequate ventilation of the working areas is provided by using a slot exhaust system very similar to a welding bench exhaust system.

Naphthalene

NAPHTHALENE is handled at Los Alamos in both the molten state and in large crystalline chunks in quantities up to 500 pounds. The chief effect that we have noted in exposed personnel is ocular irritation resulting in temporary double vision. We have used a tentative tolerance limit of 25 PPM.

Methods of sampling and analysis have been discussed in the literature by Robbins.[15] Before the installation of suitable ventilating equipment, concentrations ranging from 10-210 PPM were found. After the installation of annular slot exhaust systems, no concentrations have been found exceeding our tentative limit. During certain intermediate steps in the processing of the molten material, it is necessary for the workers to wear full face masks.

RDX

RDX (or cyclotrimethylene trinitramine) is not an acutely toxic material; the U.S. Public Health Service has suggested that the air tolerance for TNT be applied to RDX.[16] Sampling is carried out with a hand-crank impinger, drawing the air through diethylaminoethanol. In several hundred air samples analyzed polarographically, the RDX concentration has never been above 1.5 milligrams per cubic meter.

Tributyl Phosphate

TRIBUTYL phosphate is an example of the type of compound which might conceivably exert some anticholinesterase effect; Sabine and Hayes[17] of this Laboratory have indicated in a recent study that it exerts almost no activity of this type.

Tributyl phosphate is occasionally heated strongly with some fume formation; since this fume is irritating to the eyes, nose and throat, adequate local ventilation has proved necessary when it appears.

TNT

THE TOXICITY of TNT is well known. However, most of the exposure history has been collected during wartime emergencies and it is our belief that data on longtime chronic exposures associated with our operations will prove of value after several years of study.

Air is sampled for TNT dust and vapor by pulling it through a midget impinger containing diethylaminoethanol; a reddish color proportional to the TNT content develops and is measured spectrophotometrically at 490 millimicrons.[18] The results of several hundred air samples show that the exposure levels for all operations are maintained below the level of 1.5 milligrams per cubic meter suggested by the American Conference of Governmental Industrial Hygienists. In addition to standard methods of ventilation for dust and fume exposure, it is necessary in some operations to use rubber gloves to guard against skin absorption from TNT.

Summary

IN CONCLUSION we would like to bring out the following points:

1. Even in installations where the primary purpose of health organizations is the protection of personnel against radioactivity and radioactive materials, non-radioactive hazards must be recognized and controlled, whether they appear in exotic forms or not.

2. The existence of multiple hazards must be expected occasionally, particularly when one hazard is known to be radioactive in nature.

3. The cooperation of industrial hygiene and safety groups is necessary; very often groups will consult safety engineers about a situation which proves to be within the province of the industrial hygienist, and vica versa.

4. We would like to urge that experiences with unusual materials, or unusual operations on common materials, be reported whenever possible. Only in this way can the necessary fund of information be accumulated to permit safe operations in new industries and processes.

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One Man-Hour

HYGIENE ENGINEERS of the Westinghouse Electric Corporation report that of every 100,000 man-hours (that's a full year's work for 50 men) put in by employees of the Westinghouse Electric Corporation last year, less than one man-hour was lost because of industrial ailments. The industrial hygiene staff maintains a card index of over 7,000 materials used by the company in manufacturing processes and personnel equipment.

—*American Glass Review*, September 5, 1953.

Air Pollution Control
in a chromium chemicals plant

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IN A MOVE to increase capacity and modernize operating facilities at its Baltimore works, Mutual Chemical Company of America decided in 1948 to replace its old plant with a completely new one on an adjacent site. This resulted in creating the largest sodium bichromate manufacturing unit in the world. A prime consideration in the design of this new plant was the determination to utilize the most up-to-date techniques and equipment for purposes of hygiene and air pollution control, to a degree that could not have been accomplished simply by annexing control devices to existing equipment. Much thought and care were given to establishing a work-home in which employees would have a safe and healthful environment. Our present consideration, however, deals only with measures invoked to control general atmospheric contamination.

Just as wet collection of air contaminants can convert air pollution to water pollution, so the clean-up of working environment—the realm of industrial hygiene—by dry collection techniques conceivably could have resulted in more, not less, general air pollution.

To deal with the overall problem, the expert advice of the Industrial Hygiene Foundation of America was solicited. T. F. HATCH, W. C. L. HEMEON and their associates at the Foundation were consulted in connection with each major design feature, to be sure that adequate provisions were made to attain the goals desired.

Manufacturing Operations

IN PRIMARY chromium chemical manufacture, the operations are chiefly those of producing sodium bichromate. Both metallurgical and chemical processes are involved, and as might be anticipated it is largely the former which necessitates attention to atmospheric pollution control. The chemical operations are predominantly wet process and accordingly of little significance air pollution-wise.

Basically the metallurgical operation consists of mixing chrome ore with lime and soda ash, and roasting the mixture in inclined oil-fired rotary kilns. For high roasting efficiency, however, the raw materials must be finely ground and intimately mixed. More than a third of the kiln feed is finer than 40 microns in size. Thus storing, conveying, drying, grinding, proportioning, mixing, and roasting more than 900 tons of such material daily could in the aggregate result in excessive dust pollution were it not for proper means of control. Aggravating the pollution potential is the large volume of air and combustion gases that must be handled. The kilns and dryers alone account for several hundred thousand cubic feet per minute. This is worthy of special mention because dust loadings in these gases are far higher than elsewhere; it is estimated that as much as 10% of the total—approaching 100 tons daily—becomes air-dispersed within the equipment and must be eliminated before the exhaust gases finally are emitted to the atmosphere.

This volume of exhaust gases is dwarfed by the amount of air which needs to be withdrawn from the building to dissipate heat from the dryers and kilns, and maintain a reasonable temperature in the work area. Twenty-four powered ventilator fans in the roof peaks plus other incidental ventilation result in exhausting more than one million cubic feet of air per minute from

Presented at the 46th Annual Meeting of the Air Pollution Control Association, Baltimore, Maryland, May 26, 1953.

the main building. To prevent this air from entraining enough dust to cause significant air pollution was a major problem, which could only be solved by making sure the dust would be wholly contained within either operational or collecting equipment.

Air Pollution Control Measures

MECHANICAL, electrostatic and wet scrubber types of control equipment are utilized. The three illustrations to follow comprise the principal control measures employed. In addition there is incidental use of cyclones, bag filters, and wet centrifugal collectors of conventional styles, used under ordinary circumstances which do not merit detailed discussion. Insofar as possible the units chosen were pilot tested under actual operating conditions in the old plant. This was done to test their suitability both from the standpoint of effectiveness in use and to ascertain that they would not introduce aggravated industrial hygiene problems in either operational or repair maintenance.

(1) RAW MATERIALS HANDLING:

All of the solids handling equipment is enclosed and maintained under negative pressure to insure against dust leakage, and in its design every opportunity taken to encourage settling of dust within the equipment itself thus reducing the dust-collecting load.

Screw conveyors, elevators, and bins were made as tight as possible by using welded construction insofar as feasible. Each access opening to conveyors and elevators is outlined with angle frame, against which rests soft gasket material within a small channel correspondingly outlining the dust-tight cover. The covers, hinged where necessary, are held against the frame of the opening with tee-nuts. The area of each access opening is about two square feet, and air withdrawal capacity calculated on the basis of a face velocity of 250 feet per minute.

To allow free passage of air entering the system to the exhaust fan, air passages were designed carefully so that turbulent regions, tending to entrain dust, would be minimized. Thus the vertical walls of screw conveyors extend about three inches higher than the standard casing. No modification of bucket elevators was required, there being ample free cross sectional area for air flow

Fig. 1.
Right, powered ventilators along roof peak. Left center, one short and two tall kiln stacks discharging from the electro-static precipitators. Far left, capped by-pass stacks used only temporarily in kiln start-ups.

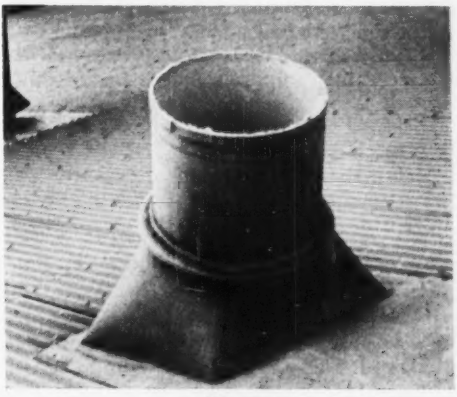

Fig. 2.
Kiln stack discharging 14,000 cfm. from electrostatic precipitator.

at low velocity. From the conveyor system the air exhaust circuits lead through large bins, where velocity is negligible and dust settling occurs to a greater extent. The suction duct of the dust collector connects to the top of the bin.

Thirteen Hersey-type bag collectors, each of 2000 cfm. capacity, are employed. Collected dust is removed from the filtering surface by a continuous back-flow of about 200 cfm. compressed air counter-current to the direction of flow of the air being filtered. Dust-laden air enters at the top of the collector and is drawn outwardly by the exhaust fan through cylindrical bags made of

piano felt. Bag dimensions are three feet diameter by seven feet long.

Dust caught on the inner surface of the bag forms a thin cake. The back blow air is introduced through a pipe ring surrounding the bag. This ring has a discontinuous narrow slot in its inner face. The ring is slightly smaller than the bag in diameter, and is continuously moved up and down slowly over the entire length of the bag. The combination of flexing and continuous compressed air jet through the slot, to which the entire bag surface is subjected several times per minute, serve both to release the collected dust and maintain a comparatively fresh and uniform filter surface. Thus this collector exhibits a constant and uniform pressure drop in the air exhaust circuit. When new bags are installed, the pressure drop increases slowly during the first two to six hours after which it remains essentially constant. The amount of pressure drop depends, in addition to flow rate, on the material being filtered, and is in the range of two to eight inches of water for the substances here involved.

(2) ROASTING:

The roasting kilns, also, are operated always under negative pressure, this being made feasible by really effective rotary seals at both ends of the kilns.

Dust-laden gases leave the roasting kilns at about 1200° F. and a velocity of 13 feet per second. Dust removal is accomplished by sequential treatment, first mechanically in settling chambers and second, electrostatically.

Each dust chamber is baffled, dividing it into two sections. Gas velocity in the first section is reduced to about four feet per second, and in the second section to about three feet per second. Inlet and outlet are so arranged that the gases make four 90° turns in passing through the chamber. This combination of velocity reduction and multiple change of flow direction is believed to result in precipitating more than 95% of the particles larger than 40 microns in size.

Six electrostatic precipitators apply the final clean-up to combustion gases from the kilns, and also from rotary dryers. Kiln gases are first passed through waste heat boilers and economizers, reducing the temperature to about 400° F. and thus protecting the precipitators from excessive temperatures. One precipitator has a capacity of 40,000 cfm. and the remainder 16,500 cfm. each.

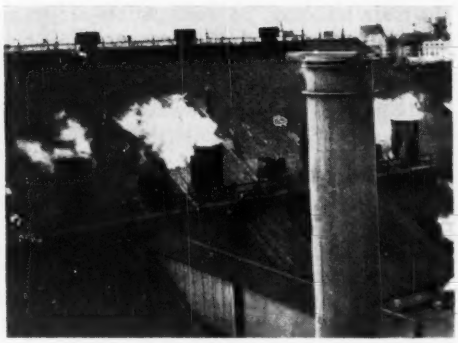

Fig. 3.
Background, three roast quenching stacks, showing steam emission.

Auxiliary equipment includes a 480-75,000-volt transformer, having five taps for voltages between 54,500 and 81,800 volts. There is one mechanical rectifier for each precipitator with transfer switches arranged so that two precipitators can operate from one transformer-rectifier system. This affords a spare in case of electrical trouble in either transformer or rectifier. The precipitators usually operate at about 55,000 volts where the output current is 150 to 175 milliamperes.

The precipitators are the plate-and-filament type in which the greater portion of the dust precipitates on the plates. There are 48 perforated plate collectors in four banks of 12 each, in series in the direction of air flow. Between each pair of plates are five filaments or ionizing wires made of No. 10 steel wire. There are more than 200 of these wires in each precipitator. The four banks of plates are divided into two sections; the first section of two banks which the gases contact acts as a primary separator, and the last two as a clean-up section. The two sections are vibrated at separate times so that when the primary section is discharging dust, the secondary section catches any which is reentrained.

Gas velocity in the precipitator is about 160 feet per minute, and the time of passage through the precipitator chamber approximately seven seconds. These precipitators were guaranteed to remove 98% of

the incoming dust, regardless of particle size. They exceed this in practical performance, which has proven most satisfactory. The loss from each kiln or dryer stack is only one to two pounds per hour.

(3) ROAST QUENCHING:

After discharge from the kilns the "roast" is cooled with recovery of sensible heat, but economy prevents cooling it much below 1000° F. Leaching out the chromium in the form of water-soluble sodium chromate after roasting, is the next processing step. Leaching is a batch operation, carried out with about 65 tons of roast per batch.

The introduction of water to this large mass of hot material—hence the term, "roast quenching"—generates large volumes of steam to be vented to the atmosphere. This is done through stacks seven feet in diameter and 65 feet high. This ventilation effectively prevents the escape of dust-laden vapor inside the building, but initially there was an excessive release of chromium through the stack. Actually the amount emitted was not large—averaging less than two pounds of sodium chromate per hour according to impinger sampling—but the bright yellow color of this material gave a yellow cast to the stack effluent and caused yellow coloration of immediately adjacent roof areas.

It was observed that chromate emission was sporadic, inasmuch as yellow color in the effluent appeared in "puffs," and usually more frequent and intense soon after quenching was started. Closer observation indicated that "puffs" occurred when the quenching solution suddenly reached a previously uncontacted portion of the hot roast, e.g., due to collecting in low pockets and overflowing into adjacent pockets.

Originally all of the quenching solution was delivered at one corner of the leaching tank. Early experiments indicated that either a slower rate of delivery or more uniform distribution over the exposed surface of the

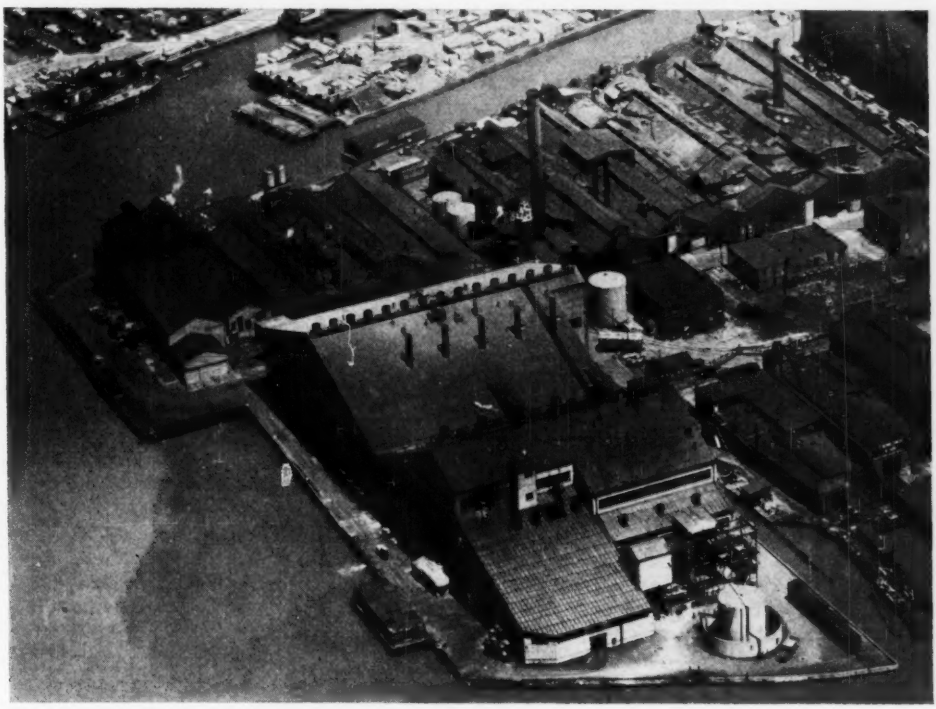

Fig. 4.
Left foreground, general air view.

TABLE I.
STACK LOSS FROM ROAST QUENCHING

Test No.	Time-of Run: hr.	Stack Velocity ft./min	Na_2CrO_4 in Gases mg/m³	Na_2CrO_4 Loss lb./hr
1	7.25	200	25.0	0.71
7	5.93	340	20.0	1.01
8	4.75	310	39.0	1.80
12	2.00	460	20.0	1.30
15	5.75	640	8.6	0.79
24	6.08	555	2.8	0.23
29	7.16	1110	3.0	0.49
33	7.00	250	1.8	0.07
34	6.82	250	3.5	0.11
35	7.03	200	2.5	0.06
36	6.22	200	1.6	0.04
37	6.30	200	2.3	0.06

roast resulted in less chromate being emitted from the stack. Distributing troughs and multiple sprays were tried. Ultimately it was found that a single spray nozzle, centrally located in the stack about 18 feet above the top surface of the roast, gave the best results. Tests confirm this reduced the chromate emission by about 80%, to an average of less than 0.1 pound per hour. The "puffs" have been eliminated; yellow coloration of the generated steam is rarely seen, and then only in the event of maloperation. The progress of solving this problem may be followed in the accompanying data tabulation (Table I).

Appraisal

BECAUSE Mutual's Baltimore facilities are situated on the upper harbor waterfront close to other industrial installations and with residential sections nearby, the avowed goal for air pollution control in the new plant was to insure against future nuisance offenses against these neighbors resulting from dust pollution of the surrounding atmosphere. We believe we have fulfilled this objective.

The accompanying photographs, taken while the plant was in full operation, are characteristic of the absence of visible plume from stack outlets.

Of interest to those who are confronted with the problem of economic justification of air pollution control is the question of cost. As specific items, the six electrostatic precipitators cost $130,000 plus installation charges, and the 13 dust collectors cost $60,000, also plus installation. Since considerations of industrial hygiene and atmospheric pollution control influenced the design of the entire plant, it is difficult to segregate their cost entirely; however, it is estimated that the net result of the measures taken for these purposes was an increase of more than 10% in the cost of this multimillion dollar project.

Industrial Hygiene Foundation

THE EIGHTEENTH Annual Meeting of the Industrial Hygiene Foundation was held November 18 and 19 at the Mellon Institute in Pittsburgh. The Medical, Legal, Chemical-Toxicological and Engineering Conference of November 18 preceded the November 19 General Meeting. DR. E. R. WEIDLEIN, President of the Mellon Institute, delivered the Address of Welcome. The keynote speaker, V. P. AHEARN, Executive Secretary, National Industrial Sand Association, chose "The Role of Government in the Employer-Employee Relationship" as his topic. The 1953 meeting was very well attended as 800 persons representing industry and the professions appeared for the two-day session.

Size Determination of Silica Particles Collected on Membrane Filters

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A method for size determinations of dust collected on membrane filters has been developed. Results indicate that the reproducibility and accuracy are good. The membrane filter is dissolved in an organic solvent, and the resultant suspension is analysed turbidimetrically. Determinations by this method are rapid and easily carried out.

THE USUAL METHOD of sampling airborne dust collects the sample in a manner that requires a microscope for a particle size analysis. Microscopic analyses are time-consuming and tedious. For routine work where there are many analyses to be done, the method is inadequate.

A turbidimetric method of size determination has been in use in this laboratory for some time, and it has been found to be reliable and rapid. The method and instrument are the development of the Eagle-Picher Research Laboratories, Joplin, Missouri.

Essentially, the instrument known as a Turbimeter consists of a concentrated beam light source, condensing lens system, a plane-sided sedimentation cell, an adjustable iris diaphragm, and a photocell for measuring the transmitted light. The output of the photocell is fed to either a microammeter or a Brown recorder. The calculations of particle size distribution are done by graphical methods. A sample calculation is given in this paper.

Membrane filters* are soluble in some organic solvents. It was decided to test the feasibility of dissolving these filters and determining the sizes of the particles collected on them. Such a procedure was found to be practicable. The method has been used in the laboratory and in the field with good results.

When using the Turbimeter under the normal conditions, a suspension of the dust sample is made using a dispersing agent such as Twitchell Base 400-H and a liquid medium such as xylene. From 50-100 mg. of dust made into a thin paste with a drop or two of dispersing agent and this paste added to 100 ml. of xylene make up the suspension. The Turbimeter is adjusted to record the characteristics for a 1.25 cm. fall. The suspension is thoroughly stirred and poured into the clean empty sedimentation cell which is in place in the Turbimeter. Light transmittance values are obtained over a period of about 15 minutes.

To calibrate for the suspension medium, a clean sedimentation cell containing 100 ml. of xylene was placed in the instrument. The ammeter or recorder was set to read 100% light transmission by adjusting the iris diaphragm. Transmission readings through the suspension under investigation were then read directly in percentage of light transmission.

The falling times for 1.25 cm. for the particle sizes of interest are calculated using Stokes' law, the value for the viscosity of the medium and the density of the particles and medium. These settling times are then used with the graphical procedures in order to arrive at the size analysis of the sample.

The method used to determine the size data of dust samples collected on membrane filters is essentially the same. A solvent for the membrane filter is used in place of the

This paper was based on work performed under Contract No. AT-04-1-GEN-12 between the United States Atomic Energy Commission and the University of California at Los Angeles.

*"Millipore" Filters manufactured by Lovell Chemical Company.

usual suspension medium, and no dispersing agent is employed. When 47 mm. diameter membrane filters are used, they are dissolved in 40 ml. of solvent. The Turbimeter is then adjusted for a 1.25 cm. fall for this volume of suspension. The calibrating liquid is 40 ml. of solvent with one filter dissolved in it.

There are a number of solvents for the membrane filter that may be used. The solvent used for this work was a mixture of 40% Cellosolve and 60% acetone. Choice of a solvent is governed by several factors. The viscosity of the resultant solution is important and the rate of evaporation should be low. When a too volatile solvent is used, there are formed currents in the suspension as evaporation takes place and normal settling is upset. The resultant solution should, of course, be clear.

The viscosity and density of the resultant solution must be known. To eliminate the necessity of determining these values for each size determination, the volume of solvent to filter size was standardized and the viscosity and density were determined at a room temperature of 25° C. Differences of several degrees from the temperature do not appreciably affect the accuracy of the determination. A number of membrane filters were weighed, and it was found that the weight differences of filters of the same size were small. For ordinary work the effect of weight differences from that used in the viscosity and density standardization may be neglected.

As mentioned above, the 47 mm. diameter filter was dissolved in 40 ml. of a 40-60 Cellosolve-acetone mixture. The resultant solution has a viscosity of 0.740 centipoise and a density of 0.860.

Experimental

IT WAS NECESSARY to know the results obtained when samples of the same dust were run in the two different liquid media. A sample of silica dust collected on a membrane filter was dissolved in the solvent and analyzed. Another sample of the same dust not collected on a filter was run in the usual manner using xylene as the medium.

From these data, shown in the following table, it is apparent that the Cellosolve-acetone medium is satisfactory. The results are easily within experimental error.

Size Range Microns Radius	Weight Dust for Size Range/ Total Weight Dust x 100	
	Xylene	Cellosolve-Acetone
0 - 0.125	0.3	0.3
0.125- 0.25	0.4	0.4
0.25 - 0.5	1.7	1.7
0.5 - 1.0	9.6	6.3
1.0 - 2.0	28.2	24.7
2.0 - 3.0	9.3	20.0
3.0 - 4.0	19.7	16.2
4.0 - 5.0	14.0	15.0
5.0 - 6.0	5.9	8.6
6.0 - 8.0	6.7	4.2
8.0 -10.0	4.2	2.6
Median Diam.	6.1 microns	5.7 microns

A number of runs was made to determine the reproducibility and the effect of amount of dust in the medium. Ideally, the dust concentration should be such that the initial light transmitted is about 30% of the light transmitted by the calibrating solution alone. If this dust concentration is used, calculations are a little easier and the best results are obtained.

Typical results obtained for silica dust collected on membrane filters which are dissolved in the Cellosolve-acetone medium are shown below.

Size Range Micron Diam.	Weight Dust for Size Range/ Total Weight Dust x 100		
	Sample No. 1	Sample No. 2	Sample No. 3
0- 1	0.2	0.2	0.4
1- 2	0.1	0.1	0.2
2- 3	0.2	0.2	0.4
3- 4	0.2	0.3	0.6
4- 5	0.4	0.5	0.8
5- 6	0.6	0.7	1.1
6- 8	2.2	2.6	3.4
8-10	4.5	5.4	5.1
10-15	38.7	39.0	33.0
15-20	32.0	35.0	37.0
20-40	20.9	16.0	18.0
Avg. Diam., Microns	17.3	16.6	16.8
Mg. Dust on Filter	24	15	5

These data show that the concentration of dust in the medium does not affect the results of the determination. The lower concentration gave an initial light transmittance value of about 85%, but good results were still obtained. The reproducibility is certainly good.

A sample of the silica dust used in the experiments above was measured using a filar micrometer on a microscope. The average diameter by weight was found to be 23.9 microns. Since optical methods give results larger by 25% to 300%, this represents good agreement between methods. The difference here is about 40%.

Summary

THE TURBIDIMETRIC analysis of a suspension obtained by dissolving a membrane filter that was used to collect a dust sample yields a particle size determination of good accuracy. The reproducibility of the results of runs on samples of the same material is very good.

If enough dust can be collected on the filter (5 mg. per 47 mm. diameter filter per 40 ml. of solution being sufficient), then this method offers a good way to get a size determination of the dust sample. The analysis may be done optically on the membrane filter, but it is more rapidly and easily done turbidimetrically.

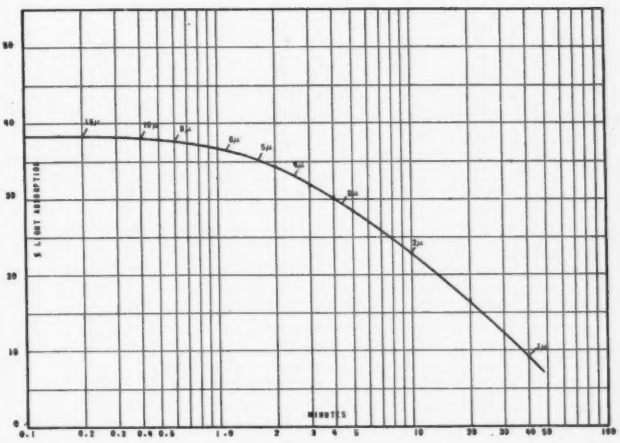


Fig. 1.

Illustrative Example

THE FALLING distance for which the instrument is adjusted is the distance from the surface of the medium in the sedimentation cell to the center of the light beam shining through the medium. The time necessary for a particle to fall this distance is called the falling time. For this work the instrument was adjusted for a 1.25 cm. fall, and the falling time for this distance was calculated for various size particles using Stokes' law. Using a viscosity value of 0.74 cp., particle density of 2.65, and a fluid medium density value of 0.860, the falling times were as follows:

Radius, microns	Time, minutes
1	39.6
2	9.9
3	4.4
4	2.5
5	1.6
6	1.1
8	0.6
10	0.4
15	0.2
20	0.1

A suspension of silica (density 2.65) in a solution of Cellosolve-acetone containing one dissolved millipore filter (density 0.860, viscosity 0.74 cp.) was run through the Turbimeter. As the suspended material settled during the run, percent light transmission readings were recorded for measured intervals of time. These values were then subtracted from 100 to obtain percent light absorption values. Below is a table of these data:

Time, Minutes	% Light Transmittance	% Light Absorption
1/6	61.8	38.2
1/3	61.8	38.2
1/2	61.9	38.1
1	63.1	36.9
2	65.6	34.4
3	68.4	31.6
4	69.8	30.2
5	71.7	28.3
7	74.4	25.6
10	77.3	22.7
20	83.8	16.2
40	91.4	8.6

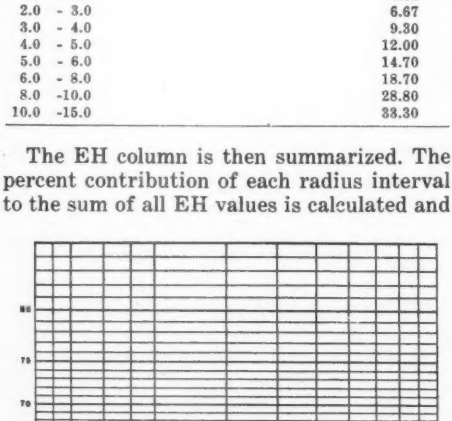
The percent light absorption values were plotted versus time, and a smooth curve was drawn through these points (Fig. 1). The falling time values were then marked on the curve. Percent light absorption values corresponding to these falling times were read and entered into the table below the graph of Fig. 2 in the column headed PA, starting at the 1-2 micron radius interval line downward through the 10-15 micron radius interval line. These values are then plotted in the graph of Fig. 2, and a curve is drawn through the points and extrapolated to zero. The remaining upper portion of the PA column is now filled in from this plot.

The differences in percent light absorption going from the smallest radius interval toward the largest are calculated and entered into the $\triangle$ A column. The $\triangle$ A

values are then multiplied by the appropriate Equivalent Hiding Factor, and these values are entered into the EH column. The Equivalent Hiding Factors as presented in "Turbimetric Particle Size Analysis" by J. R. Musgrave and H. R. Harner are as follows:

Radius Interval, microns	Factor
0 - 0.125	1.35
0.125- 0.25	1.55
0.25 - 0.5	1.90
0.5 - 1.0	2.40
1.0 - 2.0	4.00
2.0 - 3.0	6.67
3.0 - 4.0	9.30
4.0 - 5.0	12.00
5.0 - 6.0	14.70
6.0 - 8.0	18.70
8.0 -10.0	28.80
10.0 -15.0	33.30

The EH column is then summarized. The percent contribution of each radius interval to the sum of all EH values is calculated and



RADIUS INTERVAL	SAMPLE			OF		SAMPLE			OF		SAMPLE			OF	
	PA	ΔA	EH	%	CUM %	PA	ΔA	EH	%	CUM %	PA	ΔA	EH	%	CUM %
0-0.125	5	5.0	1.2	0.1	0.1										
0.125-0.5	0.9	0.9	0.9	0.1	0.2										
0.25-0.5	1.5	1.0	1.5	0.1	0.1										
0.5-1.0	2.1	0.6	1.5	0.2	0.4										
1.0-2.0	8.8	13.6	55.2	23.1	31.8										
2.0-3.0	22.6	5.8	55.5	30.5	31.1										
3.0-4.0	29.4	1.6	13.9	14.4	85.7										
4.0-5.0	31.0	2.0	26.4	11.1	77.0										
5.0-6.0	31.2	1.4	20.6	8.9	85.9										
6.0-8.0	35.6	1.3	24.3	10.4	96.3										
8.0-10.0	37.0	0.7	8.6	3.7	100.0										
10.0-15.0	38.2														
TOTALS			212.1	100.0											

Fig. 2.

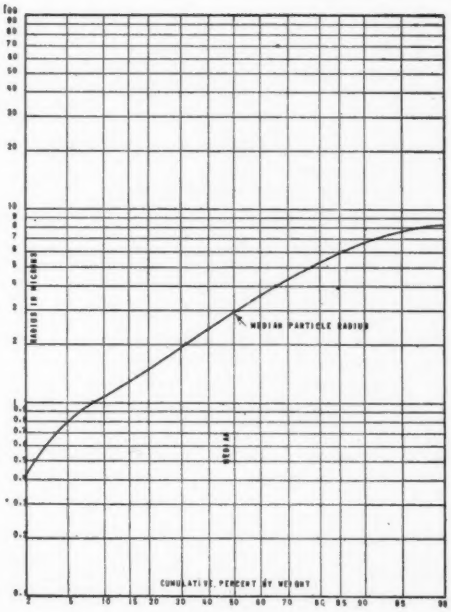


Fig. 3.

entered into the % column. This column represents the percent by weight of the particles in each radius interval.

The cumulative percent by weight of the particles in a given interval radius range (Cum % Column) is then calculated from the values in the % column. These values are plotted on log-probability paper. The median particle size is obtained from this graph (Fig. 3.). It is found to be 2.9 microns radius for this example.

A complete description of the theory and technique of this method of turbimetric analysis is to be found in the Eagle-Picher bulletin entitled "Turbimetric Particle Size Analysis" by J. R. Musgrave and H. R. Harner.

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The Electrostatic Precipitator

DILUTION METHOD OF FLOW MEASUREMENT

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WHENEVER it has been necessary to measure the air flow through an electrostatic fume and dust sampler, the measurement has involved an unknown amount of error. This is because the air flow through the precipitator is sensitive to any obstruction, so that an instrument introduced into the air stream for the purpose of measurement may disturb the air flow sufficiently to cause a departure from normal operation. The dilution technique used in this research has the advantage of measuring the air flow without causing a change in the flow pattern or offering any appreciable resistance to flow.

The precipitator is used as a suction source to withdraw a mixture of carbon dioxide and air from a tank. The gas withdrawn is replaced by room air which simultaneously dilutes the mixture remaining in the tank. The resulting depletion of carbon dioxide in the tank follows the law: $C = C_0 e^{-bt}$.* By plotting the decrease in carbon dioxide concentration with time on semilog paper, the resulting straight line allows graphical or arithmetic calculations of the constant (b) from which the air changes per minute and the volume rate of flow can be calculated.

The experimental work was done in two parts. In the first portion a known rate of dilution was used and checked against the rate calculated from the dilution formula. Since the two rates checked within 4% at several flow rates, it was felt that the technique was valid and could be applied to measuring the flow rate of a precipitator. The second part of the experimental work consisted of measuring the flow rates of two different samplers.

*See appendix for derivation, terminology, and sample calculation.

Equipment and System

THE following equipment was used: a 15 cu. ft. stainless steel tank (Fig. 1) with suitable openings, including a sampling port, an air withdrawal port, and an air entrance port located at top-center of the tank; eight-inch 1750 rpm circulating fan; rotameter; carbon dioxide gas; gas meter; Hancock ejector; smoke tube; Orsat apparatus; sampling flasks; vacuum pump; electrostatic samplers; and stopwatch.

Experimental Procedure

Checking a known rate of Dilution: The equipment was set up with the ports loosely closed. Three-and-a-half to five cu.

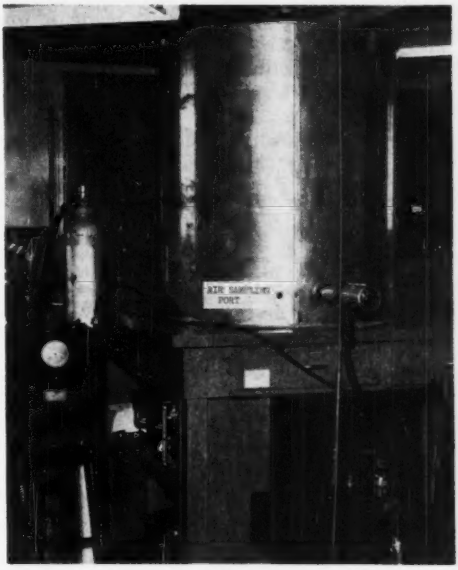

Fig. 1.
Equipment for dilution measurement.

ft. of carbon dioxide were metered into the tank through the gas meter, and the fan was started to insure complete mixture of the gases. Three 300 cc. sampling flasks were evacuated to a pressure of 1-2 mm. mercury. The rotameter was connected to the withdrawal port, and the Hancock ejector started and adjusted until the rotameter indicated the desired volume rate of withdrawal. The two-inch diameter air inlet port was checked with a smoke tube to make sure that there was an inflow of air over its entire area. With our tank, only when the circulating fan was placed directly opposite the entrance port and axial to it was it possible to prevent simultaneous inward and outward movement of gas, thereby causing excessive dilution.

The first grab sample was taken at an arbitrary zero time after the flow pattern had been established. Two or three subsequent samples were taken at exact time intervals, and finally the air entrance port was again checked to make sure that there was no outward movement of air. The grab samples were then analyzed for carbon dioxide content with the Orsat apparatus, using standard techniques, which insured accuracy to one-tenth of 1% of carbon dioxide. This limiting accuracy made it unnecessary to account for carbon dioxide present in the diluting air.

Dilution with the electrostatic precipitator: The procedure using the precipitator was similar (Fig. 1), the precipitator replacing the Hancock ejector as a suction source and the rotameter taken out of the system. The end of the precipitator cylinder projected about three inches into the tank. An air-tight seal was insured by use of a rubber stopper. The fan and precipitator were run for one to two minutes to mix the air and carbon dioxide, and to establish the flow pattern before the first grab sample was taken.

Experimental Data

RESULTS obtained using known rates of dilution and two different electrostatic precipitators are shown in Tables I and II. Part of the data is shown graphically in Figs. 2 and 3. The calculation of flow rate for both tables is based on the carbon dioxide concentration of the first and last samples obtained in each run. This calculation is illustrated in the appendix.

Discussion

THE DATA from the first part of the investigation indicate that the method will measure flow rates within 4% over the range of commercial electrostatic samplers. The data from the second portion fit a straight line as closely as the data in the first part, which justifies the conclusion that the measured values of volume rate are within 4% of the actual values. Replicate runs with instrument number 598 agree within the same limit.

It was found during the experimentation that there were several potential sources of error. They are the following: (1) inade-

TABLE I.
CHECKING TECHNIQUE FOR KNOWN RATES OF DILUTION

Volume Rate CFM	Sample Concentrations, per cent CO_2 Zero Time	End of 1st Time Interval	End of 2nd Time Interval	Time Interval minutes	Calculated Rate CFM	Difference %
1.0	13.3	9.8	6.8	5	.99	1.0
2.0	22.0	15.1	10.2	3	1.92	4.0
3.0	18.0	10.1	5.5	3	2.89	3.7
3.0	19.6	10.9	6.1	3	2.92	2.7

TABLE II.
CALIBRATING ELECTROSTATIC PRECIPITATORS BY DILUTION TECHNIQUE

Instrument Number	Sample Concentrations, per cent CO_2 Zero Time	End of 1st Time Interval	End of 2nd Time Interval	End of 3rd Time Interval	Time Interval minutes	Calculated Rate CFM
467	24.7	17.0	11.7		3	1.87
598	18.3	10.5	5.8		3	2.87
598	14.5	10.0	6.8	4.7	2	2.82
598	13.1	7.6	4.3		3	2.79
598	7.3	4.1	2.3		3	2.89

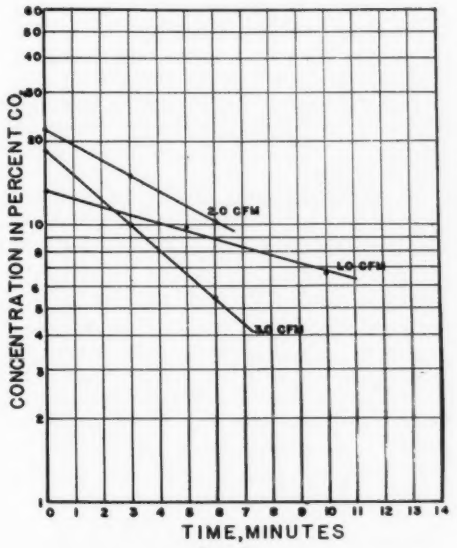

Fig. 2.
Dilution at known flow rates.

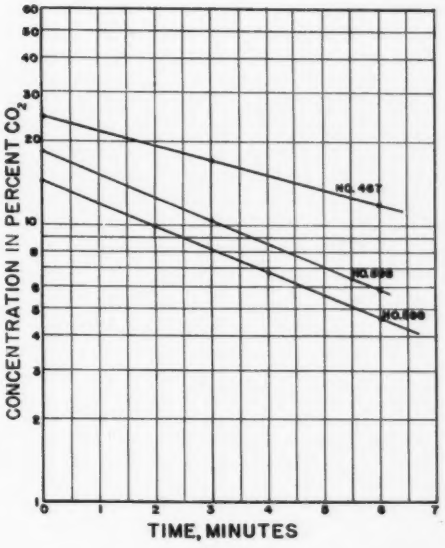

Fig. 3.
Dilution by electrostatic samplers.

quate mixing of gases in the tank; (2) excessive dilution; and (3) non-representative sampling.

The errors of inadequate mixing and excessive dilution can be avoided by following the procedures described above, especially those related to location of the circulating fan, and checking the air inlet port for direction of flow through it. The use of tanks of different shape and dimensions might require other arrangements than those described.

The possibility of taking a non-representative sample of the mixture is minimized by locating the sampling port near the outlet, which insures that the sample will be taken in the air stream leaving the tank and avoids the possibility of sampling in a stagnant area or in the jet of incoming fresh air. The sampling port must be closed when not in use.

An inherent source of error affecting the accuracy of measurement of air flow by the rotameter is the slight increase in gas density due to the addition of carbon dioxide. This greater density would make the rotameter, which was calibrated for air, indicate a flow rate up to 3% higher than the true value. This may account for the consistently negative values found in Table I.

Sources of error associated with the precipitator itself would be either: (1) an imposed pressure differential; or (2) interference with the normal flow pattern of air entering the sampling tube. The first of these considerations was shown to be negligible; a manometer indicating pressure variation between the interior of the tank and the outside showed a differential of about one-hundredth of an inch of water, an amount too small to be significant. The calculated pressure loss through the tank air-entrance port on the basis of a flat plate orifice is about 0.002 inch of water for a flow rate of three cfm. The second consideration was investigated theoretically by use of Dalla Valle's principle of similarity of contours.[1] Calculation showed that the 5% velocity contour lines extend behind the suction openings about an inch. It is therefore reasonable to conclude that at a distance of three inches from suction opening, the tank wall would have no significant effect upon the flow pattern.

The use of continuous indicating instruments, such as a microgas analyzer or a benzene indicator, which would give continuous data for the dilution of an organic vapor, were also investigated for their efficacy in the technique outlined above. By

these methods, consistent results with known dilution rates were not achieved. This was thought due to the relatively large error inherent in such sampling devices which cannot be depended on for accuracy better than about 10%. By contrast, the error of the gas analysis technique was about 4% for the lowest concentration of CO_2 involved and less than 1% for most of the samples determined. This point is of considerably more importance for a calibration of the precision herein attempted as compared with use of a similar technique for calibrating indicating instruments themselves.[2]

Summary and Conclusions

A SIMPLE and accurate calibration of flow through an electrostatic sampler can be made by using the precipitator as a suction source and measuring the rate of dilution of a known gas concentration contained in a tank of measured volume. As the electrostatic precipitator withdraws air from the tank, room air enters freely and is continuously mixed with the remaining air-gas mixture.

Such dilution follows the equation: $C/C_0 = e^{-bt}$. The data from periodic analysis of the gas mixture will plot as a straight line on semilog paper, with the slope of the line giving the air changes per minute, which can be converted to the volume rate of the air withdrawing instrument.

This technique offers the advantage that virtually no obstruction is offered to the air flow through the electrostatic precipitator. Results are reproducible within 4%.

Appendix

NOMENCLATURE:

$b = \frac{Q}{V}$ = air changes per unit time in a volume, V
C = concentration at time, t
C_0 = initial concentration at t = 0
e = base of natural logarithms
Q = volume rate of flow, cfm
t = time, minutes
V = volume of tank, cubic feet

DERIVATION OF DILUTION EQUATION:

Assumptions: (1) incoming air continuously and completely mixed with CO_2 and air in tank; (2) no storage or loss of CO_2 in tank.

Equating depletion of CO_2 in tank with the amount of CO_2 in mixture withdrawn, the basic equation is: $CQdt = -VdC$; or:

$$\frac{Q}{V}dt = -\frac{dC}{C} = bdt.$$

Integrating:

$$-\int_{C_0}^{C} \frac{dC}{C} = b\int_{0}^{t} dt; \text{ or: } -\ln\left(\frac{C}{C_0}\right) = bt;$$

$$\ln\left(\frac{C}{C_0}\right) = -bt.$$

which becomes:

$$\frac{C}{C_0} = e^{-bt}.$$

SAMPLE CALCULATION:

Precipitator #598. Three samples, three minutes apart, using first and third samples:

$$\frac{\ln C_0 - \ln C}{t} = b$$

$C_0 = 18.3\%$
$C = 5.8\%$
$t = 6$ minutes
$V = 15$ cubic feet

$$b = \frac{\ln 18.3 - \ln 5.8}{6} = \frac{2.90691 - 1.75786}{6}$$

$$= \frac{1.14905}{6} = 0.19151$$

$$Q = bV = (.192)(15) = 2.87 \text{ cfm.}$$

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THE MODERN concept of medicine in industry is the application of the principles of modern medicine to the industrial workers, sick or well, supplementing the traditional remedial methods with the newer principles of hygiene, sanitation, engineering, toxicology, and health promotion.

—From "The Importance of Industrial Medical Departments as a Management Tool" by DANIEL C. BRAUN, M.D., in *Advanced Management*, October, 1953.

Ventilation—

FOR SHIP CONSTRUCTION AND REPAIR

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IN THE CONSTRUCTION and repair of ships, ventilation is required in the work of two crafts. One of these crafts, welding, has been investigated thoroughly during the war years for health hazards, and general recommendations for ventilation control have been published by the Public Service[1] as a result. These and other investigations have made sufficient information available for the protection of welders on ship work by means of local exhaust and general ventilation.

Less has been published about the need for ventilation in the painting of ships. While much has been written about the war-accelerated, radical change in construction of ships, that is, substitution of welding for riveting, but the concurrent change from brush to spray painting has not been particularly emphasized in either general or technical literature.

Spray painting met with as much resistance from ship owners and operators as did welding, and there are some operators who still prefer brush painting even at much greater cost and time. At the present, however, about the only use for brush painting is for trimming out.

This change in method of application of paint has caused a serious potential problem for the following reasons:

(1) Increase in the application rate of paint.

(2) Increase in solvent content of paint, due to need for thinner materials for spraying.

(3) Increase in the inherent toxicity of solvents, due to the development of plastic type paints.

Spray painting of exterior surfaces of ships, either on the ways or in drydock offers no particular hazard except when using paints which have toxic metals as the pigment. This is sometimes the case, such as when red lead priming is required or anti-fouling paints are used for the areas of the hull below the water line. In these cases, suitable respiratory protection is furnished to the men exposed. Spray painting of interior surfaces and the satisfactory control can best be illustrated by two different applications which become standard procedures in the Baltimore district of Bethlehem Steel Company.

Spraying of Ballast Tanks with Bitumastic

THIS PARTICULAR job was unusual in that the material being sprayed was in the form of a viscous mass. A high pressure pump of the type used for grease lubrication served to introduce the material to the spray gun head. At this point it was atomized with air. The tanks sprayed were No. 3 and No. 5 port and starboard wing tanks which are on the sides of the ship and extend from the main deck to the keel. The dimensions are 40′ x 22′ x 44′. These tanks were originally cargo tanks but, because of operational practices, are now used as ballast tanks. The bitumastic was typical of that found in preservation coatings, and one of the most troublesome aspects of using this material is the photo-sensitizing effect that usually is inherent. In addition to this factor the spray created contained a very large amount of fine-particle mist that would rapidly have limited visibility in the tanks to a very great extent. Precautions established prior to start of this job were as follows: (Fig. 1)

(1) Painters were required to wear impermeable suits with head covering.

(2) Painters were required to wear air line respirators and goggles to protect eyes.

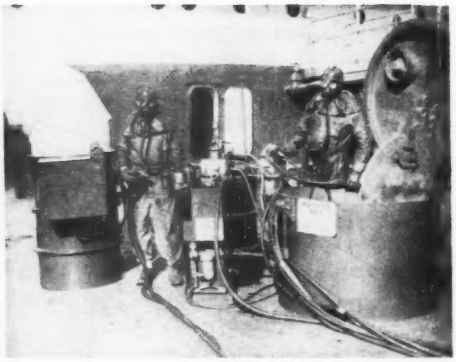


Fig. 1.

(3) Explosion-proof lighting and adequate fire protection were furnished.

(4) Ventilation was furnished by axial-flow fans of U.S. Navy Standard, Size A-6-D-1-W-5, which are rated at 5000 cubic feet per minute at three inches of water static pressure. These fans were installed to exhaust with the supply entering the tanks through the 36-inch manholes and exhausting through the Butterworth connections which were 15 inches in diameter. Tuve et al.[2] have shown that, with discharge velocities of 800 feet per minute, the entrainment ratio is 15. This, in conjunction with a throw (velocity of stream reaching 50 feet per minute) of 32 feet, gave good circulation and dilution ventilation in the tanks. (Fig. 2)

Advantages gained through these provisions have been:

(1) No need for abnormal relief for personnel.

(2) Minimum amounts of holiday eliminating touchups.

(3) In combination with engineering features productivity on this type of work has increased 30%.

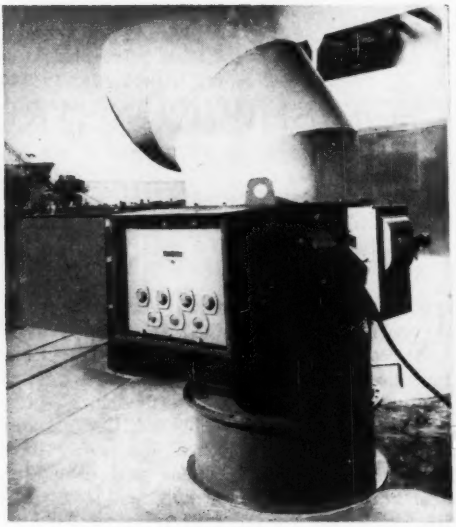


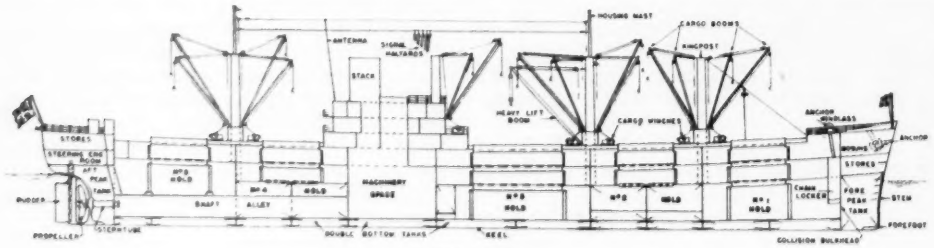
Fig. 2.

Spraying of Deep Tanks

AS PART of a routine repair and maintenance order on a Victory type ship the owners specified the sandblasting and spray painting of the No. 4 hold deep tanks. (Figs. 3 and 4) There are four deep tanks in No. 4 hold on a Victory ship. The dimensions of the tanks are as follows:

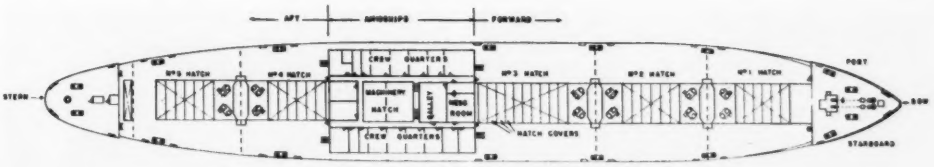
Port forward	45'x25'x11'	12,300 cu. ft.
Port aft	36'x18'x11'	7,100 cu. ft.
Starboard forward	45'x23'x11'	11,400 cu. ft.
Starboard aft	36'x16'x11'	6,300 cu. ft.

These tanks had hatches 14'6"x8'6" and trimming hatches 4'x4'. The necessary scaf-



INBOARD PROFILE

Fig. 3.



DECK PLAN

Fig. 4.

folding was erected in each tank to enable the painters to be close enough so that the spray would be wet when striking the plate. The spray painting was to consist of a vinyl type wash primer, a second coat of "liquid stainless steel" and the third and fourth coats to be of a clear vinyl resin type. These materials were all proprietary compounds and the application was experimental. The solvent was methyl isobutyl ketone and the diluent was toluene, which is typical of vinyl resins. The only previous attempt with a similar application of which the author has knowledge, was by a subcontractor at another shipyard, with a resulting explosion causing the death of two men and injury to two others. In order to prevent such an accident occurring during this application of the vinyl paints, the following procedure was established by the Operating, Safety and Medical Departments: (Figs. 5 and 6)

(1) The area around No. 4 hold was posted with signs forbidding "hot work" and smoking. A fireman was assigned to enforce these prohibitions. All matches and lighters were removed from men working in the vicinity.

(2) Workmen's shoes were examined for protruding nails, rubbers were furnished those men whose shoes could give a spark.

(3) Lighting was provided by explosion-proof portable lamps with connection boxes installed on the main deck.

(4) Suitable hoses with fog nozzles and applicators were connected and placed on the main deck and fire extinguishers were on hand.

(5) It was determined that sufficient ventilation could not be provided to the tanks to eliminate the possbile toxic hazard of the solvent fumes. Ventilation was installed in the following manner to eliminate the explosive hazard: Each of the four deep tanks was ventilated by two vane axial fans, each having a capacity of 5000 cubic feet per minute at three inches of water static pressure. These U.S. Navy Standard, size A-6-D-1-W-5, driven by five horsepower direct-drive motors. The fans were installed on planks laid over the hatch openings so they

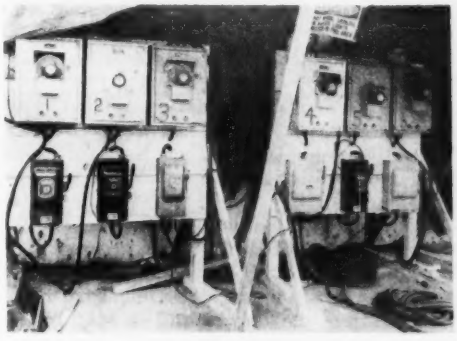


Fig. 5.

Fig. 6.

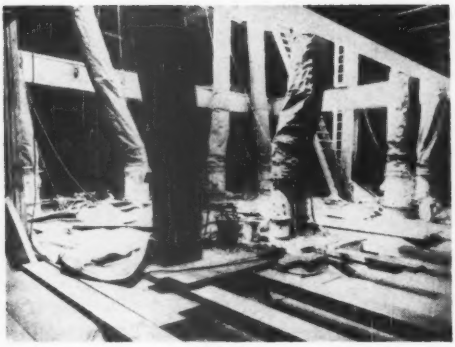


Fig. 7.

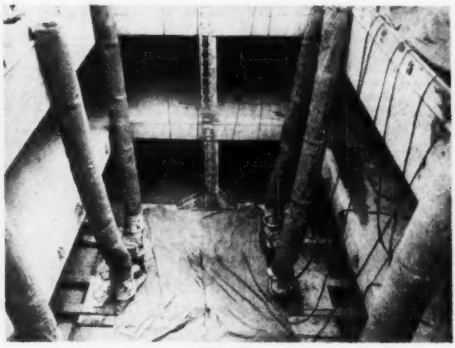


Fig. 8.

would exhaust the tank. The remainder of the hatch opening was covered with tarpaulins and boards to make the hatch as air tight as possible in order to eliminate bypassing of the air. Trimming hatches were left open in order to provide access to the tanks and to allow air to be supplied for the tanks for exhausting. The electrical control panel for the fans was set up on the weather deck and protected by a tarpaulin so that vapors could not be ignited by the switch gear. Canvas exhaust ducts 24 inches in diameter were connected to the fan discharge and these extended to the weather deck hatch coaming. The inlets to the fans had metal ducts installed with the intakes at different levels to eliminate stratification of the air. Use of the fans as exhausters, rather than supply gave two important safeguards. The first was that the access ladder was being swept at all times by uncontaminated air. The second was that by carrying the exhaust above the weather deck hatch coaming, recirculation and buildup was avoided and the 'tween deck spaces and lower hold were not contaminated with solvent vapor. (Figs. 7 and 8) This arrangement of ventilation was checked before any painting was performed and distribution in the tanks was found to be excellent due to the high velocity of air through the trimming hatch and the location of the exhaust inlets. Air volumes being handled by each fan were in the range of 10,000 cubic feet per minute. This gave a velocity of 1200 feet per minute of air entering the tanks through the trimming hatches.

(6) As an additional safeguard, a chemist, certified by the American Bureau of Shipping was retained to make constant readings of the explosive content of the air. Samples of the materials had been furnished to him in order to calibrate his instrument for the explosive range. Procedure used was to start one painter spraying in the tank and readings were taken in his vicinity. These were as follows: *Average reading near sprayer—20-30% Lower Explosive Limit; six feet and beyond sprayer—Negligible: 2-3% Lower Explosive Limit; Discharge from canvas duct—Negligible.* A second man was then started spraying in the same tank. When the sprayers were far apart the readings were as above but as they came close together the readings rose to over 50% L.E.L. in the direct exhaust. After this check only one painter was used in each tank.

(7) Since it had been decided that ventilation was practical only to the extent of controlling the explosive hazard, all painters were supplied with air line respirators. Foremen, chemists and other personnel who were required to enter the tanks were furnished chemical cartridge respirators. (Fig. 9)

(8) The four coatings were applied to all tanks routinely with production rates being five gallons per sprayer per hour for coats one and two, and seven gallons per sprayer per hour for the third and fourth coats. These rates are similar to those given by spray gun manufacturers but are misleading for ventilation calculations, as these are average rates and include time for shifting, lighting, moving around on scaffolding and other non-painting tasks. The ventilation furnished was advantageous in that no

Fig. 9.

time was needed between paint coatings for curing and this made it possible to complete the job in less than the estimated time.

Summary

IN GENERAL it is seldom possible to furnish sufficient ventilation to enclosed areas of ships which are being spray-painted to eliminate the health hazard from solvents and diluents.

It is possible and mandatory to ventilate at a rate which maintains the area free from explosive hazards. Equipment to provide this ventilation must meet the following specifications:

(1) It must be rugged as it will be handled frequently by cranes.

(2) It must be compact to minimize deck area used and storage area when not in use.

(3) It must have good static pressure characteristics as entry losses are determined by available openings and not by ventilation design.

(4) It must be well-designed for service and maintenance.

(5) It must be flexible for location.

The above requirements have been best met in our experience by the vane axial fans.

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Symposium: Instrumentation in Industrial Hygiene

University of Michigan, May 24-27, 1954

RESPONSE from manufacturers invited to participate in the University of Michigan Symposium on Instrumentation in Industrial Hygiene is most enthusiastic, as many acceptances to exhibit and participate at this May 24-27, 1954 meeting have already been received by the Institute of Industrial Health and School of Public Health, co-sponsors of the event. Early reservations from "users" include those made by physicists, chemists, engineers, meteorologists, noise investigators and safety engineers, in addition to the expected industrial hygienists and manufacturers. A complete "Information Booklet" on the Symposium has been prepared and is available to anyone interested by writing to the Director of Continued Education, School of Public Health, University of Michigan, Ann Arbor, Michigan. A detailed Symposium program will be ready for distribution early in 1954.

Purpose

THE PURPOSE of the Symposium is to present what is known, what is available and what is needed in instrumentation for industrial hygiene through the mediums of exhibits, discussions, comprehensive reviews and technical papers. This Symposium is designed to bring together instrument makers, users and experts in the field of instruments for the following purposes:

(1) To exhibit instruments to acquaint users with size, application, performance.

(2) To inform users on technical data, including limits of accuracy, maintenance and interfering conditions.

(3) To review the aims of instrumentation for industrial hygiene.

(4) To exchange information and ideas on equipment.

(5) To outline needs for improvement and for development of new instruments.

(6) To study "home assembled" devices so that these can have wider usefulness.

Participants

THE SYMPOSIUM is planned for the benefit of all of the users of sampling and measuring instruments employed in evaluating chemical and physical factors in the environment, especially industrial hygienists in industry and in official agencies. The Symposium provides an unusual opportunity to the manufacturer, safety engineer, industrial hygienist, physicist, chemist, engineer, meteorologist and noise investigator.

Program

IN ADDITION to manufacturers' exhibits, the four-day program will include discussions, comprehensive reviews and technical papers by experts in the field, users and manufacturers. Instruments will be exhibited and studied in detail in each of the following areas:

(1) Sampling and analyzing air contaminants in work places.

(2) Laboratory instruments for industrial hygiene.

(3) Atmospheric pollution evaluation.

(4) Measuring air velocity and metering air.

(5) Measuring sound and vibration.

(6) Measuring ionizing radiations.

(7) Measuring ultra-violet, visible, and infra-red energy.

(8) "Home-assembled" instruments.

The detailed Symposium Program will be ready for distribution early in 1954 and will include a list of the manufacturers exhibiting.

Symposium Publication

PAPERS presented at the Symposium will be published in an illustrated book which will include comprehensive reviews and technical papers, as well as data supplied by the makers of the instruments.

The book will be in eight sections and will cover the measurement of physical and chemical environmental factors which influence man employed in Industrial Hygiene and related fields. The sections will correspond to the program areas listed above. There will be a detailed presentation of descriptive information and technical data pertinent to each instrument displayed.

✦ President's Page

THROUGH the co-operation of Mellon Institute and Carbide & Carbon Chemicals Company I was able to attend the first conference of the British Occupational Hygiene Society in London as the invited representative of AIHA, and to visit several groups in England actively engaged in the field. The thoroughness and enthusiasm I found were quite impressive.

The conference was held November 2, 1953 in the auditorium of the London School of Hygiene and Tropical Medicine. About 160 persons were in attendance, of whom one-third were members. The Conference was opened by the Minister of Labour, the RIGHT HONOURABLE SIR WALTER MONCKTON. He spoke of the importance attached by the Ministry and in particular by its Factories Inspection Department to the profession of occupational hygiene. The Minister emphasized the co-operative nature of the profession and its positive aim of hygiene rather than simply prevention of disease. He lamented the absence of formal graduate instruction in the field.

DR. THOMAS BEDFORD delivered the Presidential Address, tracing the development of occupational hygiene from the earliest recorded mention of occupational diseases in Ecclesiastes up to the preventive activities of today. He discussed the team work which marks our current efforts and pointed out the need for training facilities.

The inaugural luncheon at the Bonnington Hotel was marked by the presence of wine, good food and the absence of speeches. At the opening of the afternoon session your President extended the formal greetings of AIHA to the new Society and presented a gavel with engraved band as a symbol of the good wishes of AIHA and of our hopes for future co-operation.

DR. S. A. ROACH, of the Pneumocomosis Research Unit, Medical Research Council, spoke of problems and progress in measuring the Worker's environment, with particular reference to dust inhalation and the variation in intake among individuals performing the same job and among different jobs in one establishment.

DR. D. G. HARVEY, of the Department for Research in Industrial Medicine, Medical Research Council, spoke of the problems and contributions of the chemist to occupational hygiene. He was particularly concerned with investigations of the toxicity, metabolism and accumulation of chemicals and he cited many examples from his own studies.

After a break for tea, J. E. BRAHAM, Engineering Controller of Imperial Chemical Industries, discussed in considerable detail the many ways in which knowledge of occupational hygiene should be utilized by the industrial designer during the planning stages of new installations. Throughout the conference discussion from the floor was active and spirited.

The next conference of the BOHS will be held in the Spring of 1954 upon the theme of maximum permissible concentrations. At that time, PROFESSOR E. J. KING, of the Postgraduate Medical School, University of London, will take office as President.

At the time of the Conference the British Occupational Hygiene Society had 80 paid members and at least 20 applications for membership had yet to be acted upon. As in AIHA, membership is open to any qualified persons devoting a major part of their time to occupational hygiene in any of the several contributing specialties. The enthusiastic beginning of the Society promises a most useful future.

It is to be hoped that some representative of the BOHS can attend our 1954 conference in Chicago. Visiting back and forth between our respective organizations can be very helpful in exchange of ideas and viewpoints.

—HENRY F. SMYTH, JR.
President, AIHA

✦ News of Local Sections

Michigan Section

THE DECEMBER 1 meeting of the Michigan Section was held at Bloomfield Hills, Michigan. "Ventilation and Safety Engineer" was the subject of a panel composed of W. G. HAZARD, Industrial Hygiene Engineer, Owens-Illinois Glass Company; K. E. ROBINSON, Heating and Ventilation Engineer, General Motors Corporation; VICTOR FREDERIKSEN, Chief Plant Engineer, Dodge Brothers Corporation and JERRY MOORE, Vice-President, Engineering Corporate Service. The discussion revolved around a paper presented by Mr. Hazard at the National Safety Congress.

Ohio Valley Section

THE OHIO VALLEY Section met in Cincinnati November 23. DR. JOHN J. PHAIR, Professor of Preventive Medicine, College of Medicine, University of Cincinnati, addressed the group on the topic "Epidemiologic Techniques in the Study of Industrial Cancer." Since 1950, DR. PHAIR has directed investigations of the carcinogenic properties of certain petroleum products under the sponsorship of the Medical Advisory Committee of the American Petroleum Institute.

Philadelphia Section

THE PHILADELPHIA Section held a joint meeting with the Industrial Medical Association of Philadelphia on November 24 at the Frankford Arsenal. The activities included a plant tour of the arsenal, dinner, a talk by COL. MARSHALL and motion pictures.

Northern California Section

THE SEPTEMBER 15 meeting of the Northern California Section was held in Oakland and featured a presentation by GEORGE TAYLOR, Institute of Inter-American Affairs. MR. TAYLOR has been in Brazil for two years engaged in promoting industrial hygiene activities. His talk briefly touched on many phases of life in Brazil including geography, climate, political situation, industrial practices, status of industrial hygiene and the chances for survival and growth of industrial hygiene activities.

A panel on the subject "Tuberculosis in Industry" was presented at the November 17 meeting. The panel included RICHARD HEAD, Executive Secretary, San Francisco Tuberculosis Association, who spoke on "Tuberculosis and Tuberculosis Case-Finding Among Industrial Workers." MISS CARMEL MCKAY, Program Director, San Francisco Tuberculosis Association, presented a paper on "Rehabilitation" and H. CORWIN HINSHAW, M.D., Clinical Professor of Medicine, Stanford University Medical School, spoke on "Recent Advances in the Treatment of Tuberculosis."

Metropolitan New York Section

"SAFEGUARDING Chemical Operations" was the title of the paper given by R. L. ALBISSER at the November 2 meeting of the Metropolitan New York Section. MR. ALBISSER, Safety Manager of Merck and Company reviewed the current measures employed in safeguarding chemical operations including new techniques for handling potentially hazardous materials.

New Jersey Section

THE NEW JERSEY Section met in Newark on October 15 to hear a paper on "The New Jersey State Department of Health Program on Air Sanitation." The speaker, WILLIAM A. MUNROE, Principal Public Health Engineer, New Jersey State Department of Health, discussed the objectives and activities of the Air Sanitation Program now being considered for adoption by the Department of Health as a routine part of its activities.

Chicago Section

THE CHICAGO Section held its first meeting of the season on September 2. The subject "Better Health for the Industrial Worker-Viewpoint of Industrial Medicine, Labor and Management" was discussed by CARL M. PETERSON, M.D., Secretary, Council on Industrial Health, American Medical Association, and HERBERT K. ABRAMS, M.D., Medical Director, Union Health Service, Inc.

J. M. MASON, Personnel Consultant, Caterpillar Tractor Company, addressed the Chicago Section at the October 7 meeting. His subject was "The Role of the Psychologist in Industry." DR. W. HUMBER, Psychological Consultant, discussed the paper.

"The Role of the Industrial Hygienist in the Control of Dermatitis" was the program subject for the meeting on November 4. WALTER SCHOLTZ, Supervisor of Hygiene Engineering Section, Allis-Chalmers Manufacturing Company gave the paper. DR. PAUL J. WHITAKER, Medical Director, Allis-Chalmers, and DR. CLIFFORD H. KALB, Consulting Allergist and Dermatologist spoke on the roles of the doctor and the consultant in the control of dermatitis.

The program was a fine example of a team approach in the control of an industrial health problem.

Rocky Mountain Section

THE ROCKY MOUNTAIN Section met in Pueblo, Colorado on October 23, 1953. The highlight of the meeting was a tour through the Colorado Fuel and Iron Corporation seamless tube mill. The mill with a capacity of more than 150,000 net tons of seamless pipe a year is one of the west's greatest industrial developments of 1953. The mill will be a major supplier of seamless steel tubing and casing for gas and oil searches in the western states and Canada.

Western New York Section

AN EXCELLENT all day session was presented October 10 in Rochester by the Western New York Section. The meeting was designed to cover a cross section of the industrial hygiene problems found in modern industry and to interest as broad a group of people as possible. Attendance at the meeting was approximately 100 persons. The following program was offered: "Dust Hazards in Industry," KARL DUNN, Corning Glass Works; "Hazards from Radioactive Materials," HANSON BLATZ, U.S. Atomic Energy Commission; "Functions of New York State Division of Industrial Hygiene," MORRIS KLEINFELD, M.D., New York State Department of Labor; "Sources of Information," FRANK A. SMITH, University of Rochester, Atomic Energy Project; "Industrial Hygiene and the Insurance Company," WILLIAM LeROCQUE, Liberty Mutual Insurance Company; "Evaluation of Chemical Exposures," FRANK A. MILLER, Eastman Kodak Company; "Ventilation in Industrial Hygiene," ROBERT H. WILSON, University of Rochester, Atomic Energy Project; "Skin Reactions from Industrial Chemicals," DAVID W. FASSETT, M.D., Eastman Kodak Company.

◆ *In the News*

FREDERICK S. MALLETTE, AIHA Secretary, has been invited to present a Clayton Lecture on air pollution before the Institution of Mechanical Engineers (London) on April 23, 1954. The Clayton Lecture was instituted under a bequest from the late James Clayton to promote the advancement of knowledge in any field relating to mechanical engineering. The terms of the bequest allow the Institution Council to extend an invitation to engineers and scientists, at home or overseas, to present a lecture on a particular subject whenever such a presentation is opportune. Interest in air pollution in Great Britain has been greatly stimulated by the severe smog of December, 1952 to which more than 4000 deaths were attributed in London alone. The Government has appointed a Committee for Enquiry into Fog composed of a number of distinguished scientists.

J. M. DALLA VALLE, Professor, School of Chemical Engineering, Georgia Institute of Technology, has been appointed a Fullbright Lecturer at the Clinica del Lavoro, University of Milan, Italy. The Clinica del Lavoro is believed to be the world's oldest clinic devoted exclusively to Industrial Medicine. PROFESSOR DALLA VALLE will spend the whole of the academic year 1953-54 on his new assignment. During his stay, he expects to visit most of the European countries and to lecture on both industrial hygiene and fine particle subjects.

DR. ANNA M. BAETJER spent two months this fall studying health conditions in Brazil, Chile, and Peru under the auspices of the World Health Organization. A large part of her time was devoted to industrial health problems and programs. She particularly enjoyed her visits with FRED VINTINNER, JACK BLOOMFIELD, and WILLIAM McQUARY, three AIHA members, who with many other persons, are making great progress in developing industrial health programs in South America.

JEAN SPENCER FELTON, M.D., Medical Director of Oak Ridge National Laboratory since 1946, has resigned to become affiliated with the University of Oklahoma as Associate Professor in the Departments of Medicine and Preventive Medicine.

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THROUGH an inadvertence, GORDON D. GINTHER was not given proper credit as one of the co-authors of the article entitled "Fluorine Exposure During Low-Hydrogen Welding," which appeared in the September, 1953 issue of the American Industrial Hygiene Association Quarterly. MR. GINTHER and JOHN J. FERRY were the authors of the article.

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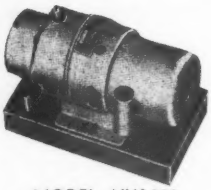

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